Geomorphology and River Hydraulics of the Teton River Upstream of Teton Dam

Teton River, Idaho

U.S. Department of the Interior
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Section 1

Introduction

The construction and subsequent failure of Teton Dam in 1976 changed the physical and biological characteristics of the Teton River canyon for 17 miles upstream from the dam site. This report documents the existing physical conditions and the changes that have occurred to the geomorphology and river hydraulics in the Teton River canyon as a result of the reservoir inundation and subsequent failure of Teton Dam.

Background

The construction of the Teton Basin Project, Lower Teton Division, was authorized by Public Law 88-583 on September 7, 1964. The Lower Teton Division was to be constructed in two phases in Fremont and Madison Counties, Idaho (figure 1). The first phase included Teton Dam and Reservoir, a powerplant, groundwater wells to provide water in dry years, and other features. This phase would have provided supplemental irrigation water for approximately 110,000 acres in the Fremont-Madison Irrigation District, for flood control operation, and for recreation and fish and wildlife mitigation measures (Schuster and Embree, 1980). The 17-mile-long reservoir was to have a total capacity of 288,000 acre-feet and a surface area of 2,100 acres.

Approximately half the land required for construction of Teton Dam and Reservoir was obtained from private landowners or the State of Idaho. The rest of the land was obtained from the Bureau of Land Management under a Reclamation withdrawal.

Filling of the reservoir began October 3, 1975, and continued until June 5, 1976, when Teton Dam failed (Jansen, 1980). The reservoir was at elevation 5301.7, about 272 feet deep at the dam, and 22.6 feet below the planned maximum pool elevation when piping caused the embankment to fail. Approximately 250,000 acre-feet of water and 4 million cubic yards of embankment material were sent down the river in about 6 hours (Lloyd and Watt, 1981; photograph A-1, in appendix A). The destruction downstream from the dam was extensive, reaching to the upper end of American Falls Reservoir, 95 miles downstream.

The failure of the dam created a situation unparalleled in Reclamation history. Legal experts analyzing the situation determined that the Federal Government was not liable for the flood damage. However, the Administration's standpoint was that the United States had a moral obligation to the flood victims, and a special appropriation was requested to pay for damages. Congress passed the appropriations bill and a subsequent bill introduced by the Idaho Congressional Delegation. Slightly less than $400 million was paid to claimants and to contractors who repaired the flood-damaged infrastructure.

The release of water from the reservoir caused extensive damage to the fisheries and riparian habitat from the dam downstream to the confluence with the Henry's Fork of the Snake River. The Idaho Fish and Game Department was compensated $1,768,708 for the loss of fish production, based on habitat loss, in this stretch of the river.

In addition to the devastation caused downstream, the portion of the Teton River canyon, which was inundated by the 17-mile-long reservoir, and Canyon Creek, a tributary which was inundated

for 3 miles, were also affected. Prior to filling the reservoir, riparian and woody vegetation was cleared in the reservoir area (photograph A-34). Wetland, upland, and aquatic vegetation and habitat conditions upstream from the dam were initially impacted as a result of the clearing and then were impacted again by hundreds of landslides that occurred during the filling and subsequent failure of Teton Dam and Reservoir.

Currently, the riverbanks are generally devoid of riparian and woody vegetation and consist almost entirely of reed canary grass. Both upland and wetland riparian and woody vegetation provide valuable habitat for many wildlife species. Following the failure of Teton Dam, the reservoir basin was reseeded with reed canary grass (*Phalaris arundinacea*) to control surface erosion.

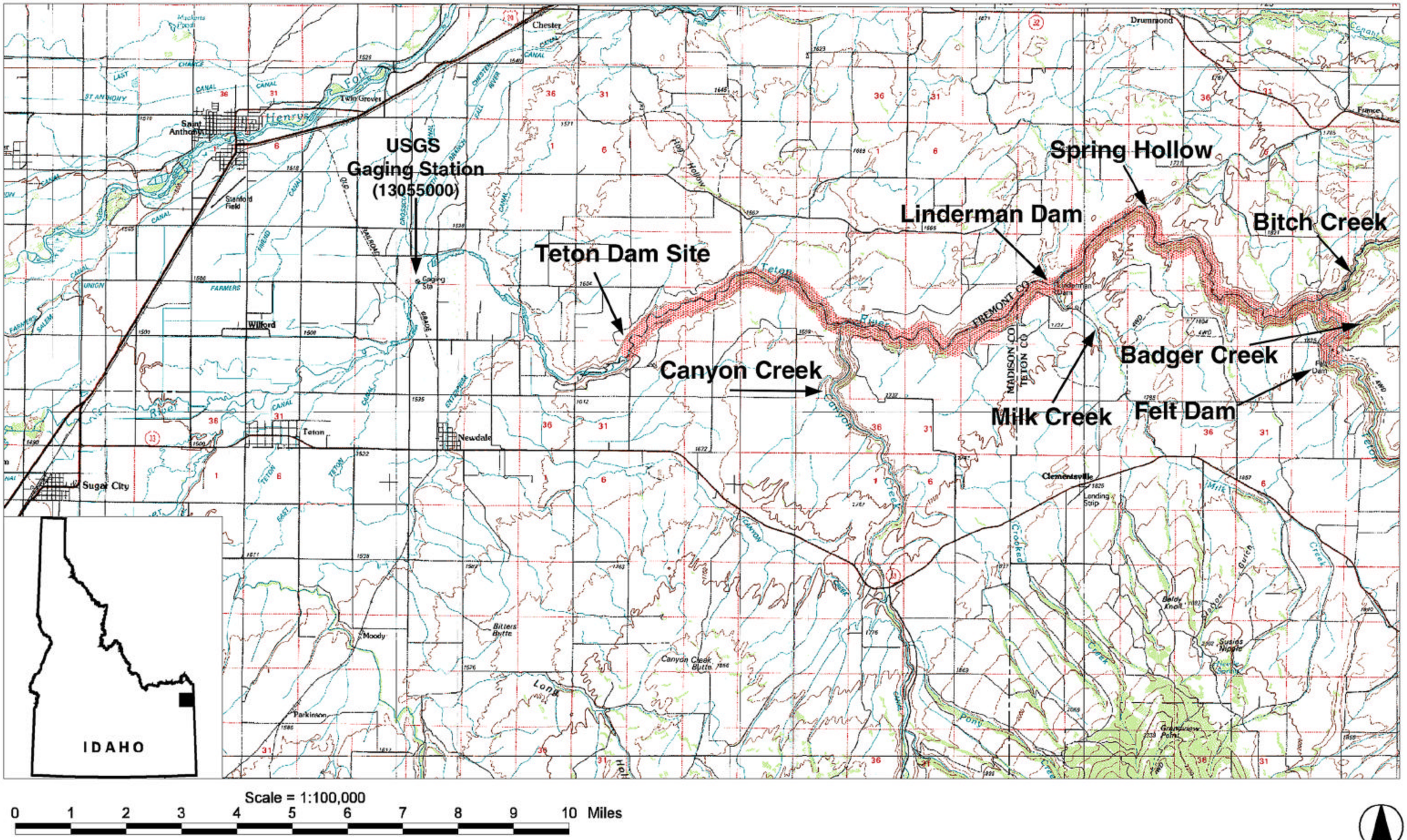
Although the reservoir upstream from Teton Dam would have completely altered the ecosystem, the landslides triggered by the dam failure are also believed to have changed the ecology of the aquatic habitat from predam conditions. The original river channel has been buried in localized areas by landslide debris. Currently, the river channel contains several long, slow pools that are backed up by short, steep cascades or rapids formed from landslide debris (photograph A-2). In addition to the reservoir-induced landslides, remnants of Linderman Dam and the submerged borrow pits upstream from Teton Dam have also impacted the predam slope of the river channel.

It was suspected that the number of pools increased as a result of the landslides, resulting in lower flow velocities and longer retention times of water flowing through the pools. This, in turn, could lead to warmer water temperatures in summer and fall and a greater potential to trap fine-grained sediment in pools.

The effects on wetland (Beddow, 1999) and upland (Beddow, in progress) habitats are being studied to determine what changes have occurred on the Teton River as a result of the Teton Dam Project. Studies involve assessing geologic, geomorphic, hydraulic, hydrologic (England, 1998), and temperature conditions (Bowser, 1999) in the reaches affected both upstream and downstream from the Teton Dam site.

Study Purpose and Objectives

The purpose of the study is to provide technical information to aid in managing Reclamation withdrawn lands in and around the Teton River canyon upstream from the Teton Dam site. The objectives of this study are to document the current physical conditions (geologic, geomorphic, and hydraulic) of the Teton River upstream from the dam site and changes that occurred from the filling of Teton Reservoir and subsequent failure of Teton Dam in 1976.


USGS
Gaging Station
(13055000)
Teton Dam Site
Canyon Creek
Linderman Dam
Spring Hollow
Bitch Creek
Badger Creek
Milk Creek
Felt Dam
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0 1 2 3 4 5 6 7 8 9 10 Miles

Section 2

Geologic History and Previous Studies

The geologic study area of the Teton River canyon is bounded between the Rocky Mountain overthrust and younger Snake River Plain downwarp (a downward bend on subsidence of a part of the earth's crust). The major geologic activities in the area are the uplift of the Teton and Snake River Ranges (the eastern extent of the Snake River Plain) and the associated volcanic activity from Island Park and the Yellowstone area. During the late Pliocene and early Pleistocene age (2.1 million years ago), the Huckleberry Ridge tuff, a 200- to 600-foot-thick flow of rhyolite from Yellowstone Caldera, was deposited over a pre-existing uneven landscape (Pierce and Morgan, 1992). The Teton River started downcutting through the rhyolite, likely due to uplifting of the Rexburg Bench in relation to the subsidence of the adjacent Snake River Plain to the west. Following incision of the Teton River into the Huckleberry Ridge tuff, a single younger basalt flow entered the Teton River canyon just downstream from the present dam site and flowed upstream, covering river gravel and filling the lower part of the canyon to a depth of about 125 feet (Magleby, 1968). The Teton River continued its active erosion cycle and extensively eroded the intracanyon basalt flow. The lower river near the dam site then changed from degradation to aggradation, resulting in the deposition of over 100 feet of sand and gravel, completely burying the remnants of the intracanyon basalt flow (Magleby, 1968).

Today, steep canyon walls typically rise 300 to 500 feet above the river in the nearly 17-mile-long reach upstream from Teton Dam that was inundated by Teton Reservoir. A 1972 contour map was developed that represents the Teton River and canyon prior to the filling of Teton Reservoir (Magleby, 1981). The water surface elevations from the 1972 contour map for 19 river miles upstream from the Teton Dam site were plotted to show the slope of the river prior to the filling of Teton Dam (figure 2). The 1972 water surface profile is based on 5-foot contours. At the upstream end (River mile (RM) 19), the Teton River canyon is narrow, resulting in a steep river slope. The canyon becomes gradually wider downstream, and the slope of the river decreases.

Typical of a river canyon widening process, the river will actively erode the toes of the canyon slopes and slope failures will occur, carrying large volumes of material to the canyon floor. Over time, the river will transport the smaller size material downstream, leaving larger boulders at the landslide areas. These large boulders often form riffles and pools that, in turn, form sediment traps for the development of islands and terraces along the river channel. There are numerous areas along the Teton River canyon walls where landslides historically constricted the river channel and created riffles and pools that can be seen on aerial photographs (appendix D). A landslide of this nature occurred between the confluences with Badger and Bitch Creeks (upstream from the former reservoir). This landslide caused a debris flow which constricted the river channel, forming a large rapid that is evident in the 1972 aerial photographs. Within the last several years, an additional landslide occurred at this location, enlarging the existing rapid. This rapid was noted during 1997 field work as being difficult to navigate due to the increased drop in water surface and large amounts of debris.

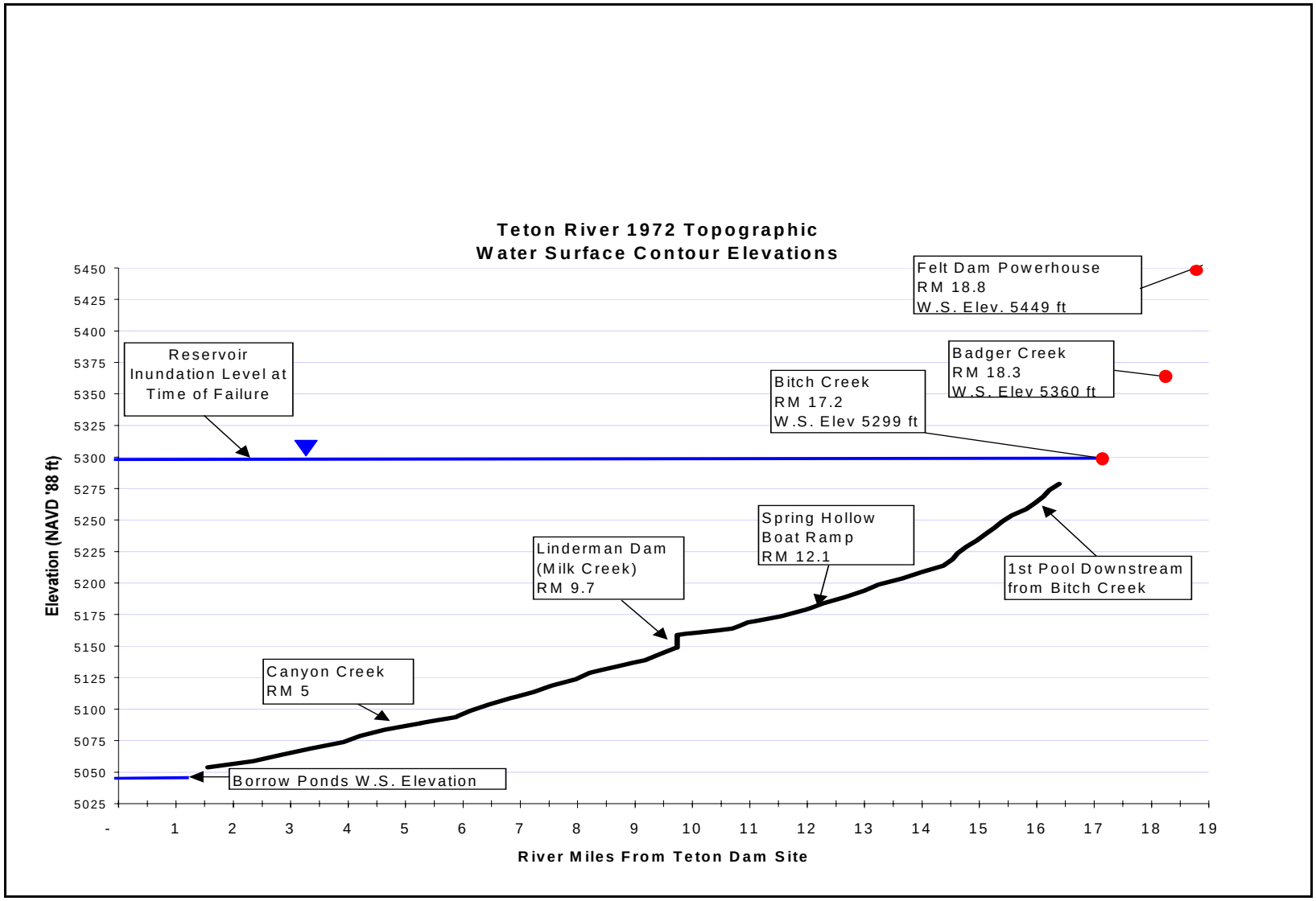

Figure 2.-Teton River orientation graph showing 1972 water surface elevation contours and the 1976 reservoir inundation reach.

Hundreds of landslides occurred along the canyon walls in 1976 during the filling and rapid drawdown of the reservoir (photograph A-5). The majority of the Teton River canyon in the reservoir area is oriented in an east-west direction. Most of the 1976 landslides were located along the south canyon walls, which are typically underlain by fine-grained sediment, as opposed to the wall on the north side, which is primarily bare bedrock.

1965 Reservoir Landslide Study

A preliminary landslide evaluation was conducted for the Fremont Reservoir site (former name for the Teton Dam and Reservoir), on the Teton River, by personnel from Reclamation's Pacific Northwest Regional Office (Magleby, 1965). The reservoir site was described as a rather steep-walled, narrow canyon eroded 300 to 500 feet into an eolian loess-covered upland. The canyon walls that would serve as the walls of the reservoir were composed of a massive to thinly laminated rhyolite and a welded ash-flow tuff. The north wall was very steep or vertical, and the south wall was less steep and composed of a poorly sorted mixture of talus, colluvium, and loess blown over the slope from the upper bench lands.

The conclusions from this evaluation were there was no strong evidence of recent landslide activity in the reservoir area, nor were there any apparent geologic conditions that would be conducive to landslides under a reservoir environment. However, based on the aerial photograph interpretation for this study, it is clear that landslides and rockfalls have been the dominant surficial process responsible for formation of the Teton River canyon over the last several hundred thousand years, and landslides and rockfills obviously occurred due to the inundation of the reservoir.

1976 Predam Failure Landslide Inspection

In May 1976, during the filling of the reservoir behind the uncompleted Teton Dam, personnel from the Pacific Northwest Regional Office performed a landslide inspection along the reservoir shoreline (Carter, 1976). The reservoir water surface was at elevation 5228.4 feet, about 95.9 feet below the maximum water surface of 5324.3 feet. Numerous landslides were observed that had developed in the loosely consolidated colluvial materials mantling the steep canyon walls.

Conspicuous slide scars and cracks were noted at 24 locations in the Teton River and the Canyon Creek arms of the reservoir (table 1). Most of the landslides varied in volume from 100 to 1,500 cubic yards. One large slide on the west slope of Canyon Creek was noted as involving an estimated 5,000 cubic yards. The thickness of the landslide was less than 15 feet at most locations.

The conclusions from this inspection were that, under reservoir filling conditions, shallow slides were to be expected on steep canyon slopes mantled with loosely consolidated colluvium. The landslides were predicted to continue until stable, in-place rock was encountered along the canyon wall. Because the vegetation was already cleared, shoreline erosion in the windblown

Table 1.—List of the landslides and their general location observed during May 1976

Type of landslide	Number observed	River miles from dam	Location on reservoir
Cracks and small slumps	minor	0 - 2.5	Teton Dam to Hog Hollow
Minor slide	1	2.5	Mouth of Hog Hollow, east slope
Slumps and minor slides	5	2.5 to 5	Hog Hollow to Canyon Creek, south rim
Scars, skin slides, large slide	4	5	Canyon Creek, west slope
Scars, cracks, skin slides	2	5	Canyon Creek, east slope
Minor slide	1	5 to 9.6	Canyon Creek to Milk Creek, south rim
Scars, cracks, slumps, minor slide	6	9.6 to 12	Milk Creek to Spring Hollow, south rim
Scars, cracks, skin slides	5	12 to approx.17	Upstream of Spring Hollow, south rim

Data taken from memorandum dated June 4, 1976, to Director of Design and Construction, E&R Center, from Regional Director, Boise, Idaho, Subject Field Inspection of Shallow Slides on Teton Reservoir, Teton Project, Idaho.

loess could occur along the reservoir rim. In some areas, the thickness of deep colluvium could be in excess of 75 feet. After these colluvial deposits became saturated under full reservoir conditions, larger landslides could develop during periods of drawdown.

June 5, 1976, Teton Dam Failure

On June 5, 1976, when the reservoir was at elevation 5301.7 feet, and during the initial filling of the reservoir, the dam failed catastrophically, releasing 250,000 acre-feet of water over a 6-hour period (Schuster and Embree, 1980). The rapid draining of the reservoir resulted in a large number of landslides on the formerly submerged, steep canyon wall slopes. For the most part, the unstable materials on the slopes were only a few feet thick and the sliding was mainly translational, often exposing bedrock at the rupture surface. In some locations, the colluvium was thicker and failed by slumping or a combination of slumping and translation. Locally along the rim, rockfalls and rock slides occurred in the welded tuff bed rock, but these failures were on a considerably smaller scale than failures in the loess and colluvium (Magleby, 1977). Slide activity was enhanced in both the unconsolidated materials and the bedrock by return of water from the saturated banks to the river after rapid drawdown of the reservoir (Magleby, 1977).

Landslide Interpretations on 1972 Base Map

Some of the landslides that were triggered by the dam failure have constricted the Teton River to a greater degree than historic conditions. In addition, a large amount of debris was deposited into

the river channel that, combined with the constriction, created or enlarged existing riffles and rapids. These new or enlarged rapids have increased the elevation of the river pools and increased the drop in water surface through the riffles and rapids. A set of topographic maps were developed, which show landslide activity along the canyon walls prior to the dam failure, during the filling of the reservoir, and after the failure of the dam (Magleby, 1981). These maps were based on 1972 topographic contours developed from 1972 photography. Additional studies were conducted to estimate the quantity of landslide material erosion.

Estimation of the Quantity of Landslide Material

Estimating the amount of landslide debris that moved to the valley floor in the Teton River canyon is a difficult task because of limited field data available. Some estimates were based on the percentage of the slopes that failed, some were based on the volume of material, and some were based on both percentage of slope and volume of material. In each case, due to limited field mapping, an estimate of the average thickness of the slides had to be used (table 2). The estimated quantity of material that moved during the 1976 landslides ranged between 2.7×10^6 yd^3 and 4.3×10^6 yd^3.

Table 2.—Summary of 1976 landslide volume estimates

Estimator	Method	Teton River	Canyon Creek	Total volume
Pre-Failure				
Reclamation/ B.H. Carter, 1976	Volume estimate, based on field inspection	19,200 yd^3	5,000 yd^3	1.97×10^4 yds^3
Post-Failure				
Reclamation/ D. Magleby, 1977	Surface area (48.5×10^6 ft^2) field study	40% (16.8×10^6 ft^2), 16 miles	50% (6.3×10^6 ft^2), 2.5 miles	4.3×10^6 yds^3
Reclamation/ D. Magleby, 1979	Volume estimate, based on aerial photographs	550,000 ft^3 (large slides only or 21% of slides)	440,000 ft^3	2.6×10^6 yds^3+ 9.9×10^5 yds^3 = 3.59×10^6 yds^3
Reclamation/ D. Magleby, 1979	Surface area (total 15.99 miles for Teton River and 2.5 miles for Canyon Creek), based on aerial photographs	10.2 miles (63%), south rim; 3.1 miles (20%), north rim (42% for river)	1.59 miles (63%), left bank; 1.4 miles (56%), right bank) (60% for Canyon Creek)	2.7×10^6 yds^3
U.S. Geological Survey/ R. Schuster, 1980	Total surface area that could slide (1,460 acres), based on aerial photographs	337 acres, south rim; 91 acres, north rim	72 acres	3.6×10^6 yds^3

Section 3

Data Collection and Analyses

Data were collected in 1997, 1998, and 1999 along the Teton River between the Teton Dam site and the Felt Dam Powerhouse, 19 river miles upstream. The data collected consist of new aerial and ground photographs, measurements of riverbed topography, water surface elevations, and bed-material particle size distributions. Additional data were collected on water quality and the riparian vegetation community and are described in separate reports (Bowser, 1999; Beddow, 1999).

Pools are defined for this study as a portion of the river that has a water surface elevation controlled by a downstream feature (such as a riffle or rapid), has a relatively flat water surface with little or no slope, deep depths, and low velocities; and is in the subcritical flow regime. Riffles are defined for this study as a reach of river with high velocities and shallow depths that are in the critical flow regime. Rapids are defined for this study as a reach of river, typically constricted relative to upstream and downstream river widths, that passes through critical depth at the upstream end and creates a large drop in water surface elevation over a short distance. Chutes are defined for this study as a portion of the river containing a series of riffles.

Twenty-seven existing (1997-99) pools and 27 rapids (or riffles) along the Teton River, between the confluences with Bitch Creek and Canyon Creek, were surveyed. The pools and rapids (or riffles) were numbered in increasing order in the downstream direction. For example, the first pool downstream from Bitch Creek is labeled pool 1 (formed by riffle 1), and the first pool downstream from Spring Hollow is labeled pool 10 (formed by riffle 10). Pool 27, the last pool, is located upstream from rapid 27, which is the last rapid before the confluence with Canyon Creek. Below Canyon Creek, the river is relatively shallow, and no major pools exist, with the exception of the borrow ponds located from RM 1.5 to the Teton Dam site. The locations of all data collected are identified by river miles from the Teton Dam site in the upstream direction (figure 2).

Aerial Photographs

Historical aerial photographs of the Teton River canyon used for this study were taken in 1957, 1972 (Reclamation; scale: 1:9,600; black/white), 1976 (Reclamation; scale: 1:12,000; color), and 1977 (Reclamation; scale: 1:12,000; color). New photographs were taken for this study in 1997 (flown by Valley Air Photos on August 30, 1997, for Reclamation; scale: 1:1,000; color). The aerial photographs most extensively used for this report were the sets taken in 1972 (predam conditions) and 1997 (existing conditions). The flight for the 1997 aerial photographs was scheduled at a time to closely match the river discharge of the 1972 aerial photographs. The mean daily discharge recorded at the U.S. Geological Survey (USGS) gaging station near St. Anthony, Idaho, was 739 cubic feet per second during the 1972 flight and 725 cubic feet per second during the 1997 flight.

Ground Photographs

Ground photographs of the Teton River canyon were taken during field trips in July 1997, August 1997, July 1998, and June and July 1999 (appendix A). During the 1997 trips, photographs were taken between Felt Dam Powerhouse (RM 19) and the Teton Dam site (RM 0). During the 1998 trip, photographs were taken between the Felt Dam and the Teton Dam site.

During the 1999 trips, photographs were taken from along the canyon rim (June) and along the river between Bitch Creek and Spring Hollow (July).

River Channel Survey Data

The purposes of collecting river channel survey data were to document the existing river channel conditions upstream from the Teton Dam site and to evaluate the amount of change since the 1976 landslides. Hydrographic data defining the water surface and channel bottom and limited topography data were collected for four reaches of river between the upstream extent of the reservoir inundation at the confluence with Bitch Creek (RM 17.2) and the Teton Dam site:

1. **Bitch Creek (RM 17.2) to Spring Hollow (RM 12.1).—**The upstream survey reach was measured in July and September 1999 and extends from the first pool (RM 16) downstream from the confluence at Bitch Creek downstream to the road access at Spring Hollow. The survey data include longitudinal water surface profiles, transverse cross-section lines, and limited ground topography on bars and islands.

2. **Spring Hollow (RM 12.1) to Canyon Creek (RM 5).—**The second survey reach was measured in 1997 and extends for 7 miles downstream from the road access at Spring Hollow (in Section 11, T. 7 N., R. 43 E.) to just downstream from the last large rapid, approximately 0.2 mile upstream from Canyon Creek (in Section 24, T. 7 N., R. 42. E.). The survey data include longitudinal water surface profiles; transverse cross-section lines; edge of water measurements through the pools, rapids, and Linderman Dam; and limited canyon topography. Some additional cross sections were measured in 1998 in this reach to fill in gaps where data were missing.

3. **RM 4.—**The third survey reach, which is relatively short (800 feet long), was surveyed in 1998. This reach is located about 1 mile downstream from Canyon Creek, at RM 4.0. The survey data include six transverse cross-section lines of the river channel and an old, high terrace on the north (right) side of the river (photograph A-18).

4. **Borrow Ponds (RM 1.5 to the Teton Dam Site).—**The fourth, and most downstream, survey reach was measured in 1997 and is known as the borrow ponds reach. The borrow ponds are submerged borrow pits that were used to supply materials for the construction of Teton Dam. The borrow ponds consist of two deep pools and a parallel river channel that can bypass a portion of flow around the downstream pond (photograph A-15). The survey data include longitudinal water surface profiles, transverse cross-section lines, edge of water measurements, and limited ground topography on the berms.

The hydrographic survey data were collected using a raft equipped with a depth sounder to measure the channel bottom through each pool, while a total station survey instrument recorded the water surface elevation and horizontal position at each measurement. (See photographs A-13 and A-14 and appendix C for more detail on survey methodology.) Survey lines consisted of cross sections perpendicular to flow, longitudinal or diagonal lines, and edge of water points.

To check the accuracy of the survey, the vertical coordinates of the 1997 Spring Hollow to Canyon Creek survey data were plotted by river mile (figure 3). In contrast to field observations of relatively flat pools that dropped slightly in elevation in the downstream direction, measured water surface elevations through pools tended to rise slightly in the downstream direction, and fluctuated up to ± 1 foot across any transverse line in a pool. This measurement error was due to the limitations of the instrument and the difficulty in tracking the moving raft, thus limiting the vertical precision of the survey measurement. This vertical error was corrected for calibration purposes by determining the average water surface elevation across each pool to eliminate the vertical fluctuations. The vertical coordinates of the 1999 Bitch Creek to Spring Hollow survey data were also plotted by river mile (figure 4). A new survey instrument used in this reach eliminated the ±1-foot fluctuations caused by the previous survey instrument.

The major focus of this study was in the river reach between the confluence with Bitch Creek and the confluence with Canyon Creek. The pool nomenclature, river mile location of each pool, pool length, mean pool elevation used for calibration, and the estimated drop through each rapid for this river reach were documented (tables 3 and 4). In addition, six cross sections were surveyed at RM 4 (downstream of Canyon Creek), representing the channel bottom and right overbank topography. The water surface elevation measured at the upstream end of this reach was approximately 5077 feet with a 2-foot drop in water surface elevation through the riffle. Just upstream from Teton Dam, 24 cross sections perpendicular to flow were measured in the 2 borrow ponds, in addition to longitudinal survey lines. The borrow ponds are a fairly level reach of river, with an average water surface elevation at approximately 5046 feet. Additional data were also measured in the diversion channel parallel to the downstream borrow pond.

Table 3.—Summary of existing conditions (1999) survey data corresponding to a discharge of 670 ft^3/s (RM 16.1 to 12.1)

Teton River section	River mile from Teton Dam site	Length of pool (ft)	Mean measured pool elevation (NAVD '88 ft)	Estimated drop in water surface to next pool (ft)
Felt Dam	19.1			
Badger Creek	18.5			
Bitch Creek	17.4			
Pool 1	16.1087 to 16.0599	260	5264.0	5.0 (rapid 1)
Cobble bars	16.0085 to 15.9195	470	5259.0	2.0 (riffle 1)
Pool 2	15.8365 to 15.5791	1,360	5257.0	13.5 (rapid 2)
Pool 3	15.3916 to 14.9399	2,390	5243.5	11.0 (rapid 3)
Pool 4	14.8452 to 14.0832	4,020	5232.5	16.0 (rapid 4)
Pool 5	13.7408 to 13.2138	2,780	5216.5	8.5 (rapid 5)
Pool 6	13.1191 to 12.7642	1,870	5208.0	6.0 (rapid 6)
Pool 6b	12.6802 to 12.6684	60	5202.0	3.0 (riffle 6)
Pool 7	12.5854 to 12.4525	700	5199.0	4.0 (rapid 7)
Pool 8	12.3613 to 12.2624	520	5195.5	2.5 (rapid 8)
Pool 9	12.2333 to 12.1341	520	5193.0	4.0 (rapid 9)

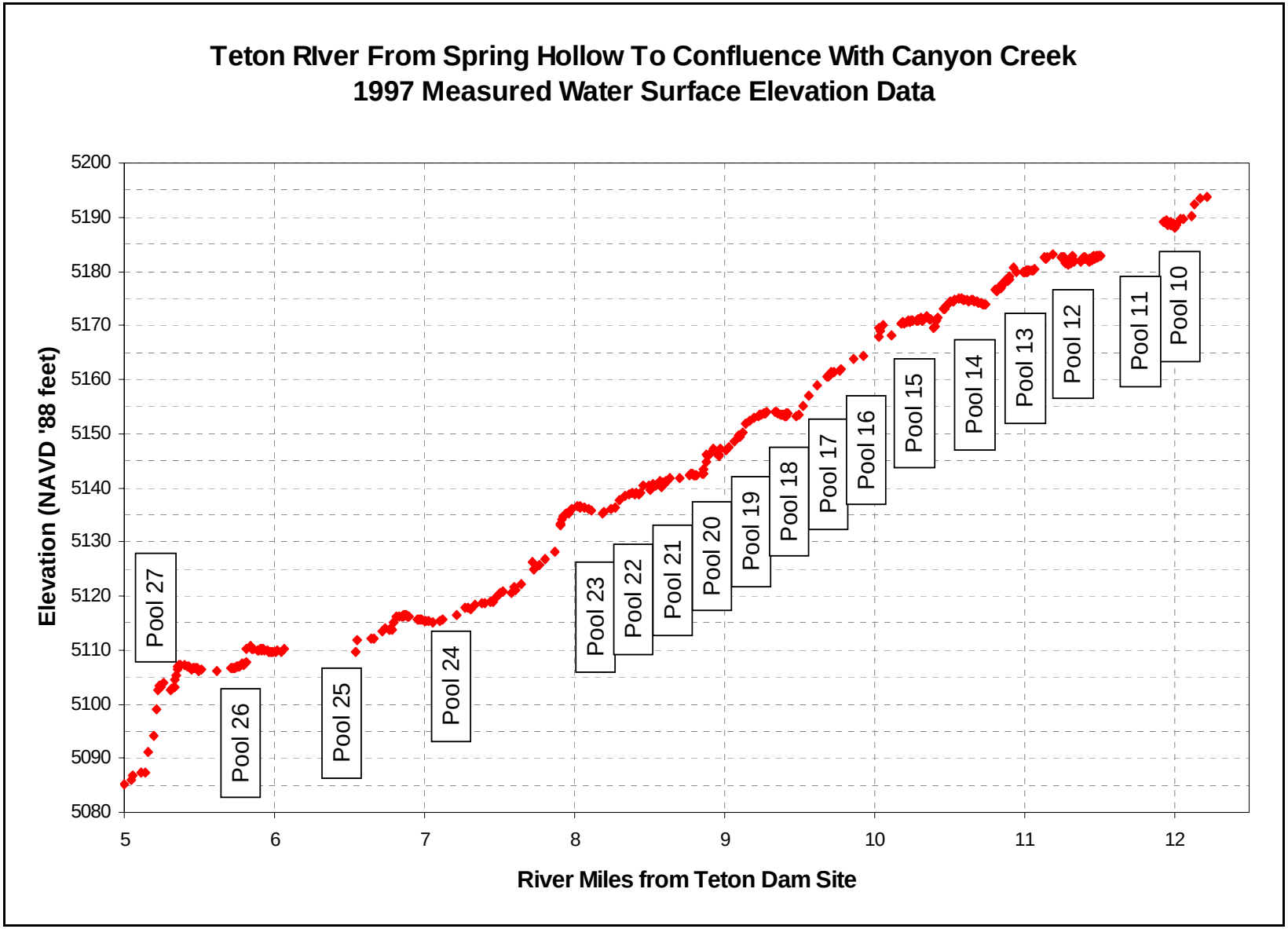

Figure 3.—Measured (1997) water surface profile for Teton River from Spring Hollow to confluence with Canyon Creek.

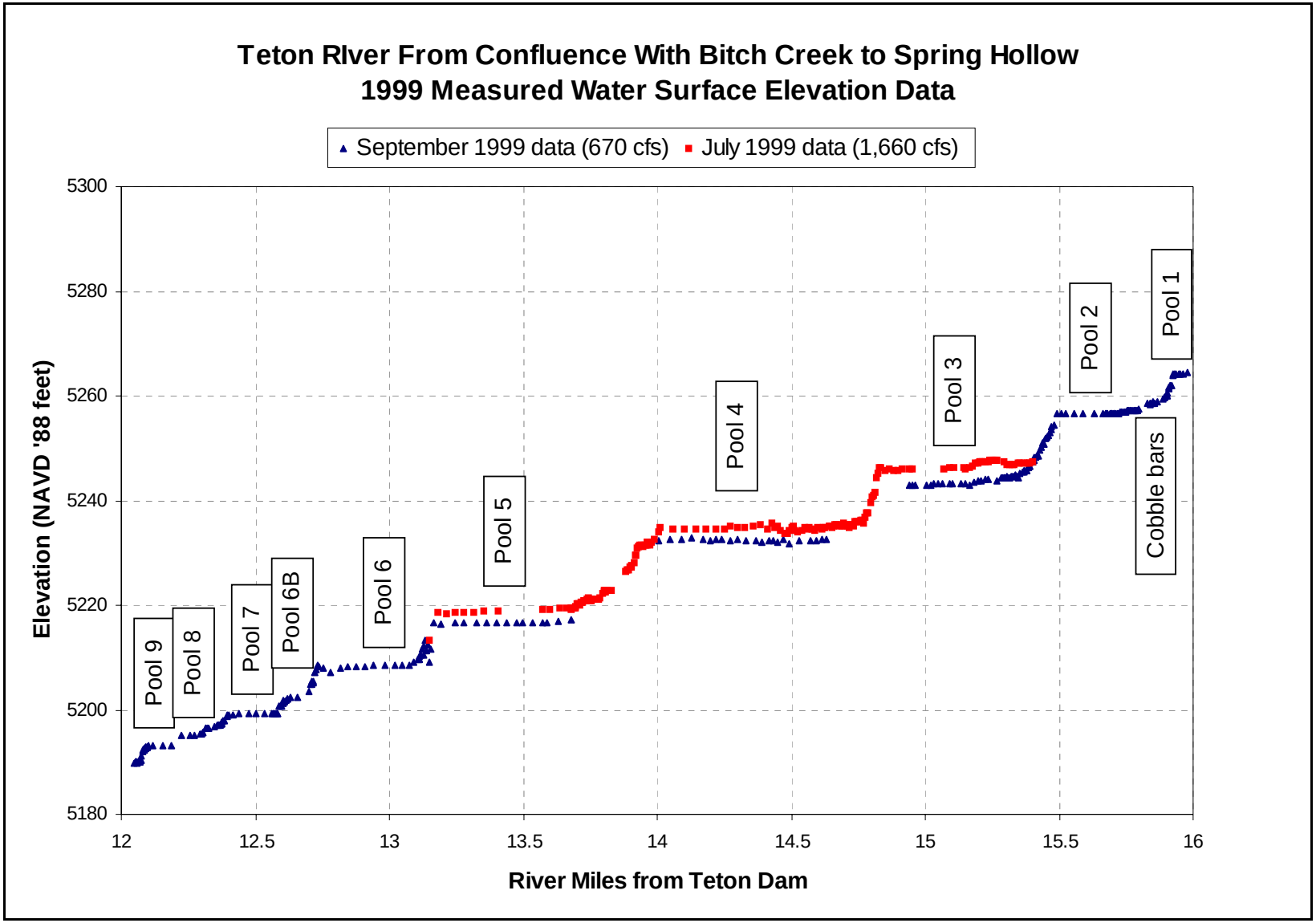

Figure 4.—Measured (1999) water surface profile for Teton River from confluence with Bitch Creek to Spring Hollow.

Table 4.—Summary of existing conditions (1997-98) survey data corresponding to a discharge of 1,400 ft³/s (RM 12.1 to 5.0)

Teton River section	River mile from Teton Dam site	Length of pool (ft)	Mean measured pool elevation (NAVD) 88 ft	Estimated drop in water surface to next pool (ft)
Spring Hollow	12.100			
Pool 10	12.063 to 11.917	770	5189.0	2.0 (riffle 10)
Pool 11	11.898 to 11.517	2,010	5187.0	4.5 (rapid 11)
Pool 12	11.504 to 11.136	1,940	5182.5	2.5 (rapid 12)
Pool 13	11.117 to 10.909	1,100	5180.0	5.5 (rapid 13)
Pool 14	10.814 to 10.492	1,700	5174.5	4.0 (rapid 14)
Pool 15	10.445 to 10.165	1,480	5170.5	6.5 (rapid 15)
Pool 16	10.032 to 9.903	680	5164.0	2.5 (rapid 16)
Pool 17	9.884 to 9.734	790	5161.5	2.0 (dam)
Linderman Dam	9.734			
Pool 18	9.722 to 9.623	520	5159.5	6.0 (rapid 18)
Pool 19	9.537 to 9.158	2,010	5153.5	7.0 (rapid 19)
Pool 20	9.063 to 8.978	450	5146.5	5.0 (rapid 20)
Pool 21	8.959 to 8.618	1,800	5141.5	2.5 (rapid 21)
Pool 22	8.552 to 8.414	730	5139.0	3.5 (rapid 22)
Pool 23	8.395 to 8.112	1,500	5135.5	3.5 (rapid 23)
Chute of riffles	7.979 to 7.502	2,100		16.0 (chute)
Pool 24	7.502 to 6.962	2,850	5116.0	5.5 (rapid 24)
Pool 25	6.943 to 5.956	5,220	5110.5	4.0 (rapid 25)
Pool 26	5.918 to 5.471	2,360	5106.5	3.0 (rapid 26)
Pool 27	5.442 to 5.347	500	5103.5	16.0 (rapid 27)
Canyon Creek	5.000		5087.5	

Bathymetric Maps

The existing channel topography data, collected in 1997-99, was used to create a set of bathymetric maps for the Teton River pools from the confluence with Bitch Creek to the confluence with Canyon Creek and in the borrow ponds just upstream of the Teton Dam site (appendix J). The maps were developed using a Geographic Information System (GIS) package that develops contours based on individual data points. Each pool has color-coded depths that represent the depth of the water corresponding to the discharge at the time the data was surveyed. The maps document: (1) the location of the measured data used to develop the maps; (2) the average daily discharge recorded at the time of the survey; (3) the mean measured water surface elevation of each pool during the survey; and (4) the locations of cross sections used in the hydraulic model for this study. The edge of water, or boundary line, for each pool was estimated based on measured data and 1997 aerial photograph analysis. Bathymetric data through each rapid was too difficult to measure; however, the length of each rapid is approximately correct on the maps. Note that in areas where there was little or no measured data, contours were not generated.

Bed-Material Particle Size Data

Bed-material sampling of river pools was collected by the U.S. Geological Survey during a separate field trip in August 1997, when the flow rate was 725 cubic feet per second. This low flow corresponded to low turbidity, which provided visibility of the riverbed at greater depths (Jacobson, 1998). Hydrolab measurements were also documented. Samples were identified by two numbers; the first number is the pool number where the sample was taken, and the second number, which increases in the downstream direction, is the sample number in that pool. The horizontal location of the samples was recorded using a hand-held Global Positioning System (GPS). Maximum particle size measurements may have been limited by sampling equipment and methodology. Bed-material samples were analyzed in the laboratory for particle-size gradations. Appendix B contains the particle-size gradations for each pool referenced to the same pool numbers used in this report.

Landslide-Material Particle Size Data

Prior to 1998, very little work had been completed on determining the size of material in the landslide debris along the Teton River. Magleby used a helicopter, in April 1977, to make some rough estimates on the size of material in the landslides along the river. Several landings were made in the canyon. Five to 25 percent of the slide debris was estimated to be composed of silt to sand-sized material. The remainder was composed of gravel-size and boulder-size blocks of rock up to 5 feet across, with the predominant size ranging from gravel to boulders 3 feet in diameter. During the 1998 field investigations, size estimates of the landslide debris covering the valley floor were made by two methods at seven sites along the river (tables 5 and 6).

Table 5.—Site locations of landslide material sampling

Site number and name	Location	Type of slide
1. Between Badger and Bitch Creeks (this slide occurred in 1997)	T. 7 N., R. 44 E., Sec. 20, SW 1/4	Shallow debris slide, mostly rock in chute, south rim
2. About 3/4 mile downstream of Spring Hollow (rapid 11)	T. 7 N., R. 43 E., Sec. 10, SE 1/4	Rock debris slide, north rim
3. Third rapid below Linderman Dam (rapid 20)	T. 7 N., R. 43 E., Sec. 21, NW 1/4	Shallow slump and earth flow, south rim
4. Madison County line (Rapid 21)	T. 7 N., R. 43 E., Sec. 20, SW 1/4	Shallow earth flow, south rim
5. Little Parkinson's Rapid (rapid 26)	T. 7 N., R. 42 E., Sec. 24, SW 1/4	Rock debris slide, north rim
6. Parkinson's Rapid (rapid 27)	T. 7 N., R. 42 E., Sec. 24, SW 1/4	Shallow slump and earth flow, south rim
7. Big Terrace, 3/4 mile downstream of Canyon Creek	T. 7 N., R. 43 E., Sec. 23, NW 1/4	Shallow sump and earth flow, south rim

Table 6.—Gradation system used for landslide debris fans

Fines to gravel	Cobbles	Small boulders	Medium boulders	Large boulders
Clay/silt sand to 3" gravel	3" to 12" rock fragments	1.0' to 3.0' rock	3.0' to 10.0' rock	> 10'

The first method was a random estimate made by walking a portion of a landslide and selecting at random an area about 50 feet square (photographs A-8, A-26, A-27, A-43; table 7). A surface count or percentage estimate was made of the various sizes of material exposed in the square. Five of the sites (sites 1 through 5) represent random estimates.

Table 7.—Random counts or percentage estimates made at the five random sites along the Teton River

Site number	Fines (clay, silt, sand)	Cobbles	Small boulders	Medium boulders	Large boulders
No. 1	5%	30%	40%	20%	5%
No. 2	15%	35%	30%	15%	5%
No. 3	30%	40%	20%	10%	0%
No. 4	20%	45%	20%	10%	5%
No. 5	15%	40%	30%	10%	5%
Average	17%	38%	28%	13%	4%

50- by 50-foot square = 2,500 ft^2 for each site.

The second method was to select an area 100 feet by 100 feet; then divide that area into quarters, making a grid system consisting of four 50- by 50-foot grids (table 8). A surface count was made of exposed materials in each of the four 50- by 50-foot grids (photograph A-24). Two of the sites (6 and 7) were used to make grid counts. Two separate grid counts were conducted at the two sites, and the grids were separated by about 200 feet. Material less than 3 inches in diameter had to be estimated as a percentage of the total surface material exposed.

Table 8.—Four grid counts made at two landslide sites along the Teton River

Site number	Fines (clay, silt, sand)	Cobbles	Small boulders	Medium boulders	Large boulders
No. 6 (A)	40%	50%	5%	4%	1%
No. 6 (B)	40%	45%	7%	7%	1%
No. 7 (A)	45%	45%	2%	7%	1%
No. 7 (B)	50%	44%	3%	2%	1%
Average	44%	46%	4%	5%	1%

100- by 100-foot square = 10,000 ft^2 for each site.

The estimates indicate that the predominant sediment sizes in the landslides along the Teton River range from cobbles to small boulders (3 inches to 3 feet, photographs A-7 and A-38). The second largest size is the fines to 3 inches, with medium and large boulders making up the smallest percentage (photographs A-8, A-9, and A-26).

This range of material sizes appears to be consistent with the material described for the slopes of the Teton River canyon prior to the construction of the dam. In the 1968 preliminary geologic report of the Teton Dam site (Magleby, 1968), the canyon sides were noted as being covered with talus and colluvium varying from 0 foot to 10 feet thick (photographs A-6, A-7, and A-38). The colluvium is a loosely compacted, poorly sorted mixture of sand- to cobble-size fragments of rhyolite in a silty matrix; the talus is composed of elongated fragments of rhyolite up to 2 feet across. Drilling of the rhyolite along the Teton River canyon indicates that the fracture and joint spacing in the rock ranged from 0.2 foot to 3.0 feet (Magleby, 1968).

Landslide Interpretations on 2000 Base Map

A previous study on landslide interpretations displayed all landslides on top of contours developed in 1972 prior to the failure of Teton Dam (Magleby, 1981). While the 1972 base map worked well for displaying predam landslide interpretations, it did not work well for displaying postfailure interpretations because after the dam failure, the topography in the canyon was altered significantly. Further, additional interpretations of the landslides were done in 1997-98 as part of this study to look at the changes that occurred since the dam failure. To provide a new base map that represents existing topography in the canyon, a set of contour maps based on 2000 aerial photography is anticipated to be developed by the end of the year. This new 2000 base map will allow existing conditions interpretations and data to be presented on existing conditions topography while the predam interpretations will remain on the 1972 base map. The interpretations for this map will be presented directly on the 2000 base map; therefore, a separate report will be generated.

Section 4

Geomorphic Interpretation

The inundation by the reservoir and the rapid drawdown following the failure of Teton Dam had a significant impact on the geomorphology of the Teton River canyon. Along portions of the 17-mile-long reservoir, landslides and rock falls from the canyon walls locally blocked or deflected the course of the river. The largest impacts from the dam failure on geomorphic conditions occurred between the first pool downstream of the confluence with Bitch Creek downstream to the confluence with Canyon Creek. Landslides downstream from Canyon Creek largely failed onto terrace surfaces and had minimal impact on the river channel.

To evaluate the changes and impacts on the river canyon geomorphology since the dam failure, aerial photographs were examined that were taken prior to the construction of the dam (1957 and 1972), immediately following the failure of the dam (1976 and 1977), and 21 years after the dam failure (1997). The geomorphic interpretation was combined with detailed channel bottom surveys of the existing conditions in the reach of the canyon just downstream from the confluence with Bitch Creek (RM 16.1) to just upstream of the confluence with Canyon Creek (RM 5.0) to identify the extent of the impact of the Teton Dam failure. In the Spring Hollow to Canyon Creek reach, channel bottom surveys and cross-sectional data were collected, during August 1997 and July 1998, when the flow was approximately 1,400 cubic feet per second (appendix E, plots E-77 to E-147). In this river reach, several larger landslides and rockfalls have created new rapids in the canyon, but they generally occurred at the same locations as previously existing rapids, large riffles, channel constrictions, midchannel bars, or islands. Pool elevations behind these newly created rapids appear to be elevated (on the order of several feet), based on field observations, aerial photography comparisons, and cross-section analysis.

Channel bottom surveys and cross-sectional data were also collected from the confluence with Bitch Creek downstream to Spring Hollow (during July and September 1999), when the flow was approximately 1,660 cubic feet per second and 670 cubic feet per second, respectively (appendix E, plots E-1 to E-76). Field observations made during July 1998 and 1999, and analysis of aerial photographs, indicate that the geomorphology impacts appear to be similar to impacts in the upstream-most section of the Spring Hollow to Canyon Creek reach (RM 12.1 to 8). In addition, the three upstream-most pools in this reach (pools 1 to 3) have filled to capacity with sediment. No impacts from the reservoir occurred in the reach upstream from Bitch Creek, the maximum extent of the reservoir at the time of dam failure.

Teton River From Felt Dam to Bitch Creek (RM 18.8, elevation 5449 feet, to RM 17.2, elevation 5299 feet; reach length = 1.6 miles (8,700 feet))

The Felt Dam to Bitch Creek reach is the narrowest and steepest section of the river in the study area. This reach is characterized by a sequence of long riffles and short pools. The average gradient through this 1.6-mile reach is about 91 feet per mile (0.017 ft/ft). Badger Creek is the only large tributary to the Teton River in this reach of the canyon. This reach was

not inundated by the reservoir and, therefore, was not affected by the dam failure. The bathymetry in this reach was not surveyed, so the details of the river channel topography are not known.

During field reconnaissance in July 1998, a large debris flow was observed on the left side of the canyon (looking downstream) between Badger and Bitch Creeks (photographs A-41, A-42, and A-43). According to biologists working on the river, this debris flow occurred sometime during the last several years. The resulting debris enlarged a previously existing rapid, thus further constricting the river channel. The slide and large rapid at this site provide a good illustration of the naturally occurring, mass-wasting processes inherent in the continuing evolution of the Teton River canyon.

Teton River From Bitch Creek to Spring Hollow (RM 17.2, elevation 5299 feet, to RM 12.1, elevation 5190 feet; reach length = 5.1 miles (27,000 feet))

The reach of the river from Bitch Creek to Spring Hollow is also relatively narrow. Long riffles and short pools are common (photograph A-39). The average gradient through this 5.1-mile reach is about 21 feet per mile (0.004). Bitch Creek is the only large tributary in this reach of the Teton River and marks the upstream extent of inundation by the reservoir. The part of the canyon where the effects of the dam failure are readily apparent begins about 1 mile downstream from the confluence with Bitch Creek. The river in this part of the canyon currently contains nine pools and rapids that were either created by, or enlarged by, the landslides associated with the inundation of the reservoir and/or the failure of the dam. Prior to the Teton Dam, three riffles (2, 3, and 4) existed in the upstream part of this reach of the river. Landslides triggered by the reservoir enlarged each of the existing riffles. A small rapid (near rapid 1) existed prior to the dam and is now inundated by a pool backed up behind a new rapid of similar size just downstream. Field observations show that the first three pools have short travel time, high velocities, and have filled to storage capacity and, therefore, cannot store any additional sediment transported by the river. The majority of sediment sizes visible in pools 1, 2, and 3 are fine grained (silt, clay, and sand) with a few cobbles present.

Much of the debris associated with these slides has been significantly modified by the river during the last 21 years. The channel at each of these sites is constricted to a greater extent than prior to the dam failure, but transport of the finer material in the slides has built new bars and islands downstream. Prior to the dam failure, the channel in the lower part of the reach contained abundant boulders that created long riffles. In addition, the channel contained numerous islands or midchannel bars. The channel was commonly very narrow in reaches, but was generally free of larger rapids. Five new rapids were created in this reach as a result of large landslides. The origin of each landslide that created the existing rapid and the conditions prior to the 1976 dam failure are listed in table 9.

Table 9.—Landslide origin of each rapid and 1972 conditions for Bitch Creek to Spring Hollow

Rapid Number	Landslide Origin	1972 Channel Conditions
1 (rapid)	Left canyon wall	Rapid existed upstream, now inundated by pool 1
1 (riffle)	Left canyon wall	Riffle existed
2 (rapid)	Both canyon walls, primarily from the right side	Riffle existed, was significantly enlarged by new slide
3 (rapid)	Left canyon wall	Riffle existed, was significantly enlarged by large slide
4 (rapid)	Left canyon wall	Several small riffles were present in the reach and the channel constricted by debris at small side canyons
5 (rapid)	Left canyon wall	Narrow channel, small riffle; channel constricted by debris from small side canyons on both canyon walls
6 (rapid)	Left canyon wall	Channel relatively narrow; contained large vegetated island just upstream of present rapid
6 (riffle)	Right canyon wall	Relatively wide channel with several large boulders in the center of the channel
7 (rapid)	Both canyon walls	Shallow riffle, enlarged by large slides
8 (rapid)	Both canyon walls, primarily from the left side	Relatively wide channel; small vegetated island along the right side of the channel
9 (rapid)	Left canyon wall	Wide shallow channel with vegetated island, landslide forming new rapid forced main channel to the right side of the canyon

Teton River From Spring Hollow to Canyon Creek (RM 12.1, elevation 5190 feet, to RM 5, elevation 5085 feet; reach length = 7.1 miles (37,000 feet))

The reach of the Teton River canyon from Spring Hollow to Canyon Creek is slightly wider than the reaches upstream, but is still very narrow compared to the reach downstream from Canyon Creek. The average gradient through the reach is about 15 feet per mile (0.003). Prior to dam construction, the channel in this reach was flanked by a narrow flood plain and low terraces. The upper 4 miles of the reach (RM 8 to 12) were characterized by a series of low riffles and deep pools. The lower 3 miles of the reach (RM 5 to 8) had a locally steep gradient that was marked by long riffles and midchannel bars and shorter pools, very similar to the present reach between Felt Dam and Bitch Creek.

A total of 18 pools and rapids now exist within this reach (appendix K). Many of these rapids were newly created by the landslides and rockfalls produced by the reservoir inundation and dam failure. In some locations, new landslide debris either enlarged previously existing riffles or blocked a channel containing previously existing midchannel bars or islands. The hydraulic drop created by each of these rapids ranges from 2 to 16 feet (table 3). The greatest change in the river channel profile is in the lower 2 miles (RM 5 to 7), where landslide debris created new rapids that have raised the water surface by over 10 feet. The origin of each landslide that created the existing rapids and an interpretation of the 1972 conditions prior to the 1976 dam failure (table 10) were documented.

Table 10.—Landslide origin of each rapid and 1972 conditions for Spring Hollow to Canyon Creek

Rapid number	Landslide origin	1972 channel conditions prior to Teton Dam
10 (riffle)	Right canyon wall	No evidence of constriction
11 (rapid)	Both canyon walls	Riffle, landslide scar on right, large boulders in channel
12 (rapid)	Left canyon wall	Riffle, boulders in channel
13 (rapid)	Left canyon wall and remobilized ancient slide	Midchannel bar, scattered boulders in channel, rockfalls on right canyon wall
14 (rapid)	Both canyon walls, primarily from the left side	No evidence of constriction
15 (rapid)	Left canyon wall	No evidence of constriction
16 (rapid)	Left canyon wall	No evidence of constriction
17 (dam)	Linderman Dam	Hydraulic drop of 10 feet created by dam
18 (rapid)	Left canyon wall	Minor riffle
19 and 20 (riffles)	Left canyon wall	Midchannel bar, rock debris along right canyon wall
21 (rapid)	Both canyon walls	Few boulders in channel upstream of current rapid location, no evidence of constriction
22 (rapid)	Left canyon wall	Three midchannel bars and boulders evident in channel
23 (rapid)	Left canyon wall	Series of shallow riffles
Chute of riffles	No landslides	Series of riffles similar to 1997 conditions
24 (rapid)	Left canyon wall	Small riffle evident
25 (rapid)	Left canyon wall	Several riffles evident
26 (rapid)	Right canyon wall, small amount from left side	Riffle, large longitudinal island just downstream
27 (rapid)	Left canyon wall	Steep riffles evident; large longitudinal islands downstream

Along the entire 7.1-mile length of this reach, landslides and rockfalls are ubiquitous, but most have been subsequently modified or originally had a minimal impact on the channel. Many of the slides in the reservoir basin of Teton Dam were limited in their extent to the surfaces of the narrow flood plain, on the broader terrace surfaces, or along the canyon walls. Slides originating on the south-facing slopes primarily consist of rockfalls or shallow translational slides (photographs A-6 and A-7). The largest slides in this reach almost exclusively originated on the northerly facing canyon walls and typically blocked or deflected the channel. These slides moved large volumes of debris from the canyon walls to the canyon floor, where it was made available for transport by the river during higher flows. The dramatic increase in available sediment thus indirectly impacted the channel elevation and pool depths. Analysis of the 1976, 1977, and 1997 aerial photography indicates that these slides were subsequently overtopped and have been substantially eroded in the years since the dam failure. However, the rapids that persist in the canyon today are composed of debris from these slides.

The lateral extent and depth of each slide in the canyon can be directly related to the mean grain size and total volume of material that was available on the canyon wall at any given site. Deposits preserved along the south-facing slopes typically consist of steep talus cones and rockfalls (photographs A-12, A-21). Conversely, the north-facing slopes in many places are blanketed by thick colluvium and very well-developed, fine-grained soils formed in loess derived from the canyon rim (photographs A-5, A-11). The development of soil on these slopes is enhanced by the finer-grained character of the parent material, greater available moisture, and corresponding vegetation relative to the south-facing slopes. In a natural setting, this side of the canyon would be relatively more stable than the south-facing canyon wall because the north-facing slopes are more gentle, the soils are thicker, and the vegetation is denser (photograph A-2). However, because of the character of the deposits on the north-facing slopes, when they were inundated by the reservoir, they formed larger slides. In contrast, Canyon Creek was also severely impacted by landslides caused by the dam failure, but these landslides have not been modified to the same extent as landslide debris along the Teton River. Canyon Creek is a lot narrower and the gradient is steeper, on average, than the Teton River, but the drainage basin area, type of flows, and peak discharges are much less than those on the Teton River.

Linderman Dam

Linderman Dam was constructed across the Teton River at the confluence with Milk Creek sometime between 1957 and 1972 (based on analysis of aerial photographs). The right abutment of the dam is in volcanic rock forming the vertical canyon wall; the left abutment and much of the foundation is on the Milk Creek alluvial fan-delta. The fan-delta, formed at the mouth of Milk Creek, has forced the river along the north (right) side of the canyon and has constricted the river channel. This channel configuration certainly existed at this location for many thousands of years prior to the dam construction. A large pool (measured in 1997) with a maximum depth of 27 feet along the right side of the channel immediately downstream from the remnant dam supports this interpretation.

Based on contour elevations from the 1972 Teton Reservoir basin topographic map, the hydraulic drop across Linderman Dam (while in operation) was 10 feet. This drop formed a pool that backed up water 3,600 feet upstream, through the current locations of pools 15, 16, and 17. In 1972, the water surface elevation just upstream from Linderman Dam was approximately 5165 feet (at a discharge of 1,000 cubic feet per second). Due to the construction of Teton Dam and Reservoir, the operation of Linderman Dam was stopped, and portions of the dam were removed.

Linderman Dam is now partially breached, and the average water surface elevation just upstream from the dam is 5161 feet (at a discharge of 1,000 cubic feet per second). This indicates that the water surface elevation just upstream from Linderman Dam is about 4 feet lower today than in 1972 (see figure 7 in next section of report). The current hydraulic drop through Linderman Dam is only 2 feet. If the dam created a hydraulic drop of 10 feet in 1972,

the upstream water surface is now 4 feet lower than in 1972, and the current drop is only 2 feet. Four feet of drop still needs to be accounted for to match 1972 conditions. This suggests that rapid 18, the first rapid downstream from Linderman Dam, has increased the elevation of the pool downstream of Linderman Dam (pool 18) by 3.5 feet from the 1972 conditions.

The structural remnants of Linderman Dam are composed of concrete that is eroded and vertical pipes within the dam that are exposed and protrude into the flow (photograph A-32). Also, a horizontal concrete beam in the center of the dam still extends across the river at about the level of the water surface (photographs A-31, A-32). At lower flows, the water surface is just below the bottom edge of the concrete beam. The beam is at least partially inundated at higher flows. Even though the beam may extend across a portion of the water surface, the water velocities under the beam would be high and pose a hazard to boaters on the river.

Teton River From Canyon Creek to the Borrow Ponds (RM 5 to RM 1.5)

The river through this 3.5-mile reach is significantly wider than it is through the upstream reaches. The channel consists of a sequence of short riffles and long, shallow pools that meander between broad, flat terraces (photograph A-18). The physical setting in the river canyon through this reach today is about the same as it was prior to the construction of Teton Dam. Even though several landslides occurred in this reach due to dam failure in 1976, the debris from these slides is primarily limited to the surface of adjacent terraces and did not reach the river. No major rapids were formed in the main channel in this reach of river. The only exception to this generalization is at the upstream end of the reach, where two very extensive landslides impinged on the channel. Both slides occurred on the northerly facing canyon slope at sites of previous ancient slides.

Teton River Through the Borrow Ponds Just Upstream From the Teton Dam Site (RM 1.5 to RM 0.4, elevation 5046 feet; reach length = 1.1 miles (5,800 feet))

The river through this reach prior to dam construction was characterized by a meandering channel and broad, flat terraces. The gravel terraces were used for construction material in the dam. The borrow pits excavated during construction of Teton Dam create two deep pools connected by a narrow channel (photograph A-15). The downstream pool has a maximum depth of 43 feet and a maximum top width of 380 feet. The upstream pool has a maximum depth of 36 feet and a maximum top width of 760 feet. The downstream pool is partially divided by a narrow berm. A narrow side channel that contains a portion of the flow runs parallel to the borrow ponds along the right side of the canyon. This diversion channel was used to bypass water around the downstream pool during the construction of Teton Dam. Together, the borrow ponds contain a total volume of about 1,000 acre-feet (1.6 million cubic yards).

Section 5

Hydraulic Modeling and Analysis of the Teton River Channel

A computer model was used to predict hydraulic properties (water surface elevation, depth, mean velocity, and travel time of water) along the Teton River canyon. The U.S. Army Corps of Engineers' Hydrologic Engineering Center's River Analysis System (HEC-RAS) model (version 2.2, Brunner, 1997) was applied to four reaches:

1. The Teton River from Bitch Creek to Spring Hollow, RM 16.1 to 12.1, both predam (1972) and existing conditions (1999).

2. The Teton River from Spring Hollow to Canyon Creek, RM 12.1 to 5.0, both predam (1972) and existing (1997-98) conditions.

3. A short reach of the Teton River below Canyon Creek at RM 4, existing conditions (1998).

4. The borrow ponds, RM 1.5 to 0.4, existing conditions (1997).

In addition to modeling existing conditions, the predam channel hydraulics between Bitch Creek and Canyon Creek were also modeled based on estimated predam channel geometry. Comparisons between predam and existing hydraulic properties and channel capacity were made based on the model results. River miles (RM) upstream from Teton Dam were used to identify the locations of cross-section lines and rapids within each modeled reach to provide a consistent method of identification. The bathymetric maps provided as an attachment to this report show the locations of all cross sections developed for modeling (appendix J).

Hydraulic Model

The HEC-RAS model performs water surface profile and other hydraulic calculations for one-dimensional steady flow. The model predicts river stage and other hydraulic properties at each cross section along the river and for any specified discharge. The steady flow component of the HEC-RAS model is capable of modeling subcritical, critical, supercritical, and mixed-flow regimes. Along the 17 river miles of the Teton River being studied, a combination of pools, riffles, chutes, and rapids exists. For this study, the model was forced to work in the subcritical and critical flow regimes. Supercritical flow does occur within localized areas of the rapids, but not as an average condition across the rapid or between cross sections. Therefore, the detailed hydraulics within each rapid are beyond the scope of this study.

Several types of coefficients are used in the HEC-RAS model to determine energy losses. Friction losses associated with roughness are set using the Manning's n value. Manning's n values are determined based on the channel bed roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of the river channel, stage and discharge, seasonal change, temperature, and suspended material and bedload.

Discharges presented in the hydrologic analysis (England, 1999) were used in the model to evaluate hydraulic properties of flood peaks for the 2, 5, 10, 25, 50, and 100-year floods, and the median flows for May, June, July, August, and September. These flow values (table 11) were based on USGS gaging station data from the Teton River gage site near St. Anthony, Idaho (Gage Station No. 13055000).

Table 11.—Discharges used in hydraulic model simulations

Teton River near St. Anthony, Idaho

Discharge (ft^3/s)	Description
660	Discharge at which 1999 survey data were measured between Bitch Creek and Spring Hollow
725	Discharge at which 1997 aerial photographs were taken
739	Discharge at which 1972 aerial photographs were taken
1,000	Typical summer discharge
1,200	Discharge at which 1997 survey data were measured in the borrow ponds
1,400	Discharge at which 1997 survey data were measured between Spring Hollow and Canyon Creek

Peak discharge flood frequency estimates

Peak discharge (ft^3/s)	Return period (years)	Annual exceedance probability (%)
3,440	2	50
4,680	5	20
5,430	10	10
6,280	25	4
6,860	50	2
7,410	100	1

Median (50-percent exceedance) discharges for summer months based on mean daily flows

Discharge (ft^3/s)	Month
1,430	May
1,910	June
1,060	July
742	August
629	September

Teton River from Bitch Creek to Canyon Creek (RM 16.1 to 5)

Existing Conditions (1997-99) Hydraulic Model

The HEC-RAS model was applied to the entire reach of the Teton River from just downstream of the confluence with Bitch Creek to Canyon Creek to create an existing conditions (1997-99) hydraulic model. Survey data (1997-99), field observations (1998-99) and aerial photographs (1997) were used to develop the existing conditions model. Twenty-seven pools were identified in this reach (pool 6 has two parts - A and B). The pools are numbered in increasing order from the upstream end (pool 1 - just downstream of the confluence with Bitch Creek at RM 16.1) to the downstream end (pool 27 - just upstream of the confluence with Canyon Creek at RM 5.0). An additional section just downstream of pool 1 that contains two long cobble bars was also modeled (labeled as cobble bars).

The hydraulic model was divided into two reaches: Bitch Creek to Spring Hollow (Pools 1-9) and Spring Hollow to Canyon Creek (Pools 10-27). Cross-section locations are identified by river miles from the Teton Dam site. Each cross section can also be identified by the pool it was surveyed in, followed by the sequential cross-section number within the pool (increasing in the downstream direction). For example, in pool 1, five cross sections were surveyed. The upstream-most cross section would be 1-1 (RM 16.11), the next downstream cross section would be 1-2 (RM 16.09), and so forth. The riffles and rapids that presently form the 27 pools in this reach include drops in water surface of 2 to16 feet (refer to tables 3 and 4).

The landslide debris fans that form the riffles and rapids act as the hydraulic control for each pool. Therefore, every pool water surface elevation is a function of the water surface elevation at the top of the corresponding rapid. The water depth at these hydraulic control sections is at the minimum specific energy (critical depth) and can be computed directly because it is only a function of the channel geometry and discharge (not channel roughness). This means that the hydraulics in each pool are independent of one another.

The drop in water surface elevation through the chutes, riffles, and rapids was measured during the surveys. The wetted width of these sections were measured in the field or estimated from the aerial photographs. However, the details of the channel-bottom topography through the high-velocity chutes, riffles, and rapids are not well known because of the inability to survey these sections. Therefore, the model's hydraulic predictions through these short, high-velocity reaches may not be very accurate and are not reported in this study.

To model the hydraulics through each rapid, two cross sections were developed, one at the top of the rapid (upstream end) representing the hydraulic control, and the other at the bottom of the rapid (downstream end) representing the start of the next pool downstream (figure 5). The importance of the cross section at the bottom of the rapid is to define the water surface slope through the rapid. The water surface elevation at the bottom-of-rapid cross section is entirely dependent on, and essentially equal to, the water surface elevation of the next cross section

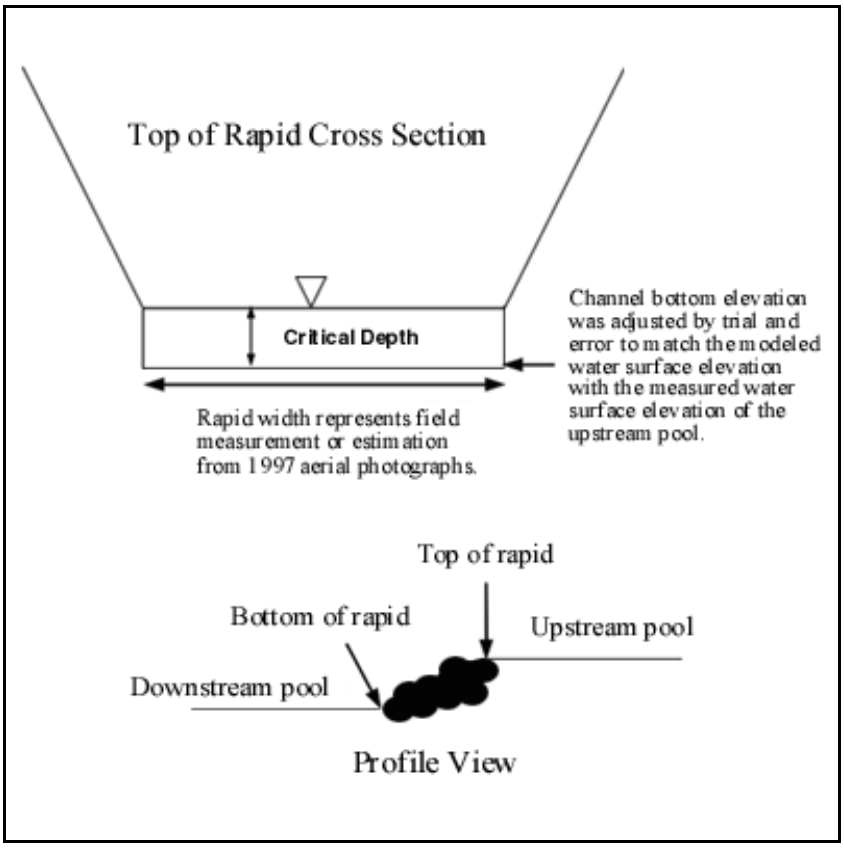

Figure 5.—Illustration of rapid cross section developed for hydraulic model and profile view of rapid section.

downstream (cross sections are relatively close). Also, the water surface elevation at the bottom-of-rapid cross section has no effect on the water surface elevation at the top of the rapid because the top of the rapid is a hydraulic control section. Therefore, the water surface elevation is not sensitive to the exact cross-section shape at the bottom of the rapid.

A simple trapezoidal shape was assumed for the overbanks for the top and bottom rapid cross sections with a rectangular section added to the lower portion to represent the rapid area (figure 5). The cross-section width for the top of each rapid was set equal to the width measured in the field or estimated from 1997 aerial photographs. The depth of the rectangular portion for the top of each rapid was set equal to the computed critical depth for that section (based on width and discharge). The cross-section width for the bottom of each rapid was set to be the average of the width at the top of the rapid and the width of the next measured cross section in the downstream pool. The channel-bottom elevation for the section at the downstream end of the rapid was set equal to the thalweg elevation of the next measured pool cross section.

Additional cross sections were interpolated by the HEC-RAS model to fill in gaps where there were long distances between measured cross sections. A downstream boundary condition (necessary for the subcritical flow regime computations) of critical depth was used at the downstream-most cross section for each model. For the Bitch Creek to Spring Hollow model, rapid 9 was used as the downstream boundary location. For the Spring Hollow to Canyon

Creek model, the last rapid (rapid 27) upstream from Canyon Creek was used (photograph A-21). The travel time for water was also computed, based on velocity and length of each pool. A hydraulic summary of the travel time, mean velocity, and maximum depth for each pool is presented (tables 12 and 13).

To calibrate the model, the channel-bottom elevation for the hydraulic controls (upstream end of each rapid section) was adjusted by trial and error until the modeled water surface elevation in the upstream pool (formed by the rapid) matched the mean water surface elevation measured in the field (at a discharge of 670 cubic feet per second for the Bitch Creek to Spring Hollow model and at 1,400 cubic feet per second for the Spring Hollow to Canyon Creek model).

Once the model is calibrated, the hydraulics for any discharge can be computed through the river reach. To evaluate the hydraulics at a typical summer discharge, the model was also run at a steady flow of 1,000 cubic feet per second (table 12).

Water Surface Profiles.—Several plots were generated from the output data computed by the hydraulic model. Longitudinal water surface profiles are provided that were computed for the flood peaks corresponding to a typical summer discharge of 1,000 cubic feet per second and the 2- and 100-year floods (figures H-1 and H-2) and the median flows for May, June, July, August, and September (figures H-3 and H-4).

Based on the model results, the water surface elevations in the pools raise 2 to 3 feet when flows increase from 1,000 cubic feet per second to the 2-year flood of 3,440 cubic feet per second, and another 2 to 3 feet when flows increase to the 100-year flood of 7,410 cubic feet per second. During the summer months, when flows fluctuate, on average, from 629 to 1,910 cubic feet per second, pool elevations fluctuate less than 1 foot.

Mean Velocity.—Mean velocity versus river mile was plotted for the flood peaks corresponding to a typical summer discharge of 1,000 cubic feet per second and the 2- and 100-year floods (figures H-5 and H-6). The graphs show how the velocities are fairly consistent through the deep pools, but increase rapidly to high levels as the water passes through a rapid or riffle.

The modeled flood peaks result in a range of pool velocities from 1 to 7 feet per second. Although the 100-year flood peak of 7,410 cubic feet per second is more than double the 2-year flood peak of 3,440 cubic feet per second in flow magnitude, only a small increase in velocity of just over 1 foot per second results in most pools. Pool velocities are typically a maximum of 2 feet per second during summer.

Table 12.—Hydraulic summary table for existing conditions from Bitch Creek to Canyon Creek at a discharge of 1,000 ft³/s

	River mile from Teton Dam site	Number of survey lines used in model	Length of section (ft)	Travel time (hrs)	Mean velocity (ft/s)	Maximum depths (ft)
Felt Dam	19.1		-	-	-	-
Badger Creek	18.5		-	-	-	-
Bitch Creek	17.4		-	-	-	-
Pool 1	16.1087 to 16.0599	5	260	.1	1.5	17
Cobble bars	16.0085 to 15.9195	5	470	.1	1.1	11
Pool 2	15.8365 to 15.5791	7	1,360	.2	1.6	8
Pool 3	15.3916 to 14.9399	10	2,390	.3	2.0	13
Pool 4	14.8452 to 14.0832	15	4,020	1.2	.9	15
Pool 5	13.7408 to 13.2138	14	2,780	1.1	.7	19
Pool 6A	13.1191 to 12.7642	9	1,870	.8	.6	20
Pool 6B	12.6802 to 12.6684	2	60	.1	4.2	4
Pool 7	12.5854 to 12.4525	4	700	.2	1.0	10
Pool 8	12.3613 to 12.2624	2	520	.1	1.6	9
Pool 9	12.2333 to 12.1341	3	520	.1	1.4	10
Spring Hollow	12.1	-	-	-	-	-
Felt Dam	19.1		-	-	-	-
Badger Creek	18.5		-	-	-	-
Bitch Creek	17.4		-	-	-	-
Spring Hollow	12.1		-	-	-	-
Pool 10	12.063 to 11.917	3	769	0.1	1.4	8
Pool 11	11.898 to 11.517	4	2,013	0.5	1.1	10
Pool 12	11.504 to 11.136	7	1,941	0.6	0.9	18
Pool 13	11.117 to 10.909	2	1,100	0.2	1.8	12
Pool 14	10.814 to 10.492	3	1,702	0.5	0.9	16
Pool 15	10.445 to 10.165	3	1,479	0.7	0.6	21
Pool 16	10.032 to 9.903	3	681	0.1	1.7	11
Pool 17	9.884 to 9.734	3	794	0.4	0.6	14
Linderman Dam	9.734		-	-	-	-
Pool 18	9.722 to 9.623	2	524	0.3	0.6	26
Pool 19	9.537 to 9.158	4	2,005	0.7	0.8	11
Pool 20	9.063 to 8.978	1	450	0.1	1.4	10
Pool 21	8.959 to 8.618	4	1,801	0.4	1.2	10
Pool 22	8.552 to 8.414	2	728	0.2	1.1	8
Pool 23	8.395 to 8.112	4	1,498	0.3	1.4	11
Long chute of riffles	7.979 to 7.502		2,097	0.1	3.9	-
Pool 24	7.502 to 6.962	6	2,851	0.4	2.0	8
Pool 25	6.943 to 5.956	9	5,215	1.4	1.0	14
Pool 26	5.918 to 5.471	6	2,359	1.2	0.5	19
Pool 27	5.442 to 5.347	2	504	0.2	0.8	12
Canyon Creek	5.000		-	-	-	-
Canyon Creek to borrow ponds	5.000 to 1.490		19,765	-	-	-
Borrow ponds	1.490 to .4		7,867	-	-	-

Predam (1972) Conditions Hydraulic Model

To create a hydraulic model of predam conditions prior to the 1976 landslides, existing cross-section data were adjusted, based on estimated changes in the channel bottom (detailed in appendix K). The aerial photographs were used to determine which, if any, ripples and rapids existed prior to the 1976 landslides. The channel bottom elevations of pools 1, 2, and 3 did not need to be altered to re-create predam water surface elevations, only the rapids needed to be removed. However, the lower two-thirds of pool 4 needed to be lowered significantly to re-create predam water surface elevations that corresponded to the 1972 contour elevations. In pools 5 to 9, only one cross section at the upstream end of pool 5 had to be lowered, along with the rapids to re-create predam water surface elevations.

It was determined that all the rapids had been either newly created or enlarged from the 1972 conditions (refer to tables 9 and 10). The 1976 landslide debris raised the channel bottom and constricted the channel width in rapid locations. Typical channel widths in 1972 were about 200 feet, but 1976 landslides have often constricted the river to half this width at rapid and riffle locations. Based on aerial photograph analysis and field observations, it was also determined that there were four locations between Bitch Creek and Canyon Creek where the river had not changed since 1972. These locations were upstream of pool 1, near Spring Hollow, the long chute of riffles downstream from pool 23, and the bottom of rapid 27 at the end of the modeled reach. Linderman Dam was the only portion of the river that had a higher water surface elevation in 1972 than the existing water surface elevation. In 1972, Linderman Dam created a 10-foot drop in water surface and formed a 3,600-foot-long pool upstream. Linderman Dam has since been partially removed. The remainder of the dam causes a 2-foot drop in water surface but does not significantly back up water past pool 17.

To calibrate the model of predam conditions, the existing water surface elevation (at 739 cubic feet per second) was compared to the water surface elevation contours of the 1972 topographic maps (developed at 739 cubic feet per second). In locations where the water surface elevations did not match, existing cross sections were altered so that the modeled water surface elevation would match 1972 topographic map water surface elevation contours (figures H-11 and H-12). Alterations consisted of adjusting channel bottom elevations and top widths to represent estimated predam conditions prior to the constrictions caused by the 1976 landslides. Notice that the modeled predam water surface still has a riffle and pool-type profile.

At the upstream end of the reach, a rapid just upstream of rapid 1 formed a pool behind it in 1972 and is now inundated. If rapid 1 is removed to re-create predam conditions, the 1972 rapid still results in a pool water surface, similar in elevation to what rapid 1 creates today.

With the exception of Linderman Dam, from pools 10 to 24, only the channel-bottom elevations of the rapid cross sections were lowered to create a water surface profile that matched the 1972 profile at the top or middle of the pool. The cross section representing Linderman Dam was raised to recreate the 1972 water surface when the dam was in operation. In pools 25 to 27, pool and rapid cross sections were widened (where constrictions did not exist in 1972) to have an average channel top width of 200 feet and lowered to match the 1972 water surface profile. The plots in appendix E show the changes made to the existing cross sections in pools 25 to 27 to create the 1972 channel bottom. Changes made at rapid cross sections are not shown because of the simple trapezoidal shape.

Comparison Between Existing (1997-98) and Predam (1972) Conditions

To evaluate the changes in modeled water surface and thalweg profiles from predam (1972) to existing (1997-98) conditions, plots were developed based on a typical summer discharge of 1,000 cubic feet per second (figures 6 and 7). The red lines show where the existing channel bottom is higher today than it was in 1972. In pool 4 (RM 14.1 to 14.8) and pools 25-27 (RM 5.3 to 6.9), the water surface and channel thalweg have significantly increased due to landslides in 1976. In addition, several of the rapids are higher in elevation today, causing longer pools to form upstream than the short pool and riffle sequence common in 1972. The 1972 water surface is lower than existing conditions in all reaches of the river except for upstream of Linderman Dam (pools 16 and 17 – RM 9.7 to 10.0).

The mean velocity versus river mile was plotted for the 1997 and 1972 conditions at 1,000 cubic feet per second (figures 8 and 9). In pools 1, 8, and 9 (RM 16.1, and RM 12.1 to 12.4, respectively), the predam velocities are identical to existing conditions, indicating that these pools existing to near the same depths at which they exist today. In pools 2-7 (RM 12.5 to 15.8), the predam velocities were higher than existing conditions. The velocity profiles indicate several riffles served as hydraulic controls in these pools in 1972, in different locations than some of the 1976 landslides. These riffles are now inundated, due to the raised water surface elevation of the pools as a result of the 1976 landslides. The predam velocities are slightly higher in pools 10 to 13 (RM 12.1-10.9) and pools 18 to 22 (RM 9.7-8.4), and slightly lower in pools 14 to 16 (RM 10.8-9.9), where Linderman Dam was backing up water in 1972. Downstream from pool 22 (RM 8.5-5.3), velocities in the predam model are up to 6 feet per second higher than under existing conditions. This is because the rapids forming these pools were not present in 1972.

Teton River From Canyon Creek to Borrow Ponds (Representative Section at RM 4)

A hydraulic model was created for a short reach of river downstream from Canyon Creek at RM 4. Although only 800 feet long, this reach of river is representative of the shallow pool-riffle sequence present in the reach of river from Canyon Creek downstream to the borrow ponds. This reach of river channel was relatively unaffected by landslide debris. The majority of debris fell onto terraces on either side of the river channel and finer sediment most likely entered the river channel and was immediately transported downstream. No large rapids were formed in this reach from 1976 landslides.

Two cross sections were surveyed upstream and downstream from a short riffle at RM 4 (appendix F). In addition to channel bottom topography, the right overbank was surveyed. The right overbank consists of wide terraces that were modeled to determine what high flows would overtop the terraces. A Manning's roughness coefficient of 0.035 was used. The assumptions of normal depth, subcritical flow, and a channel slope of 0.002 were used for the downstream boundary condition.

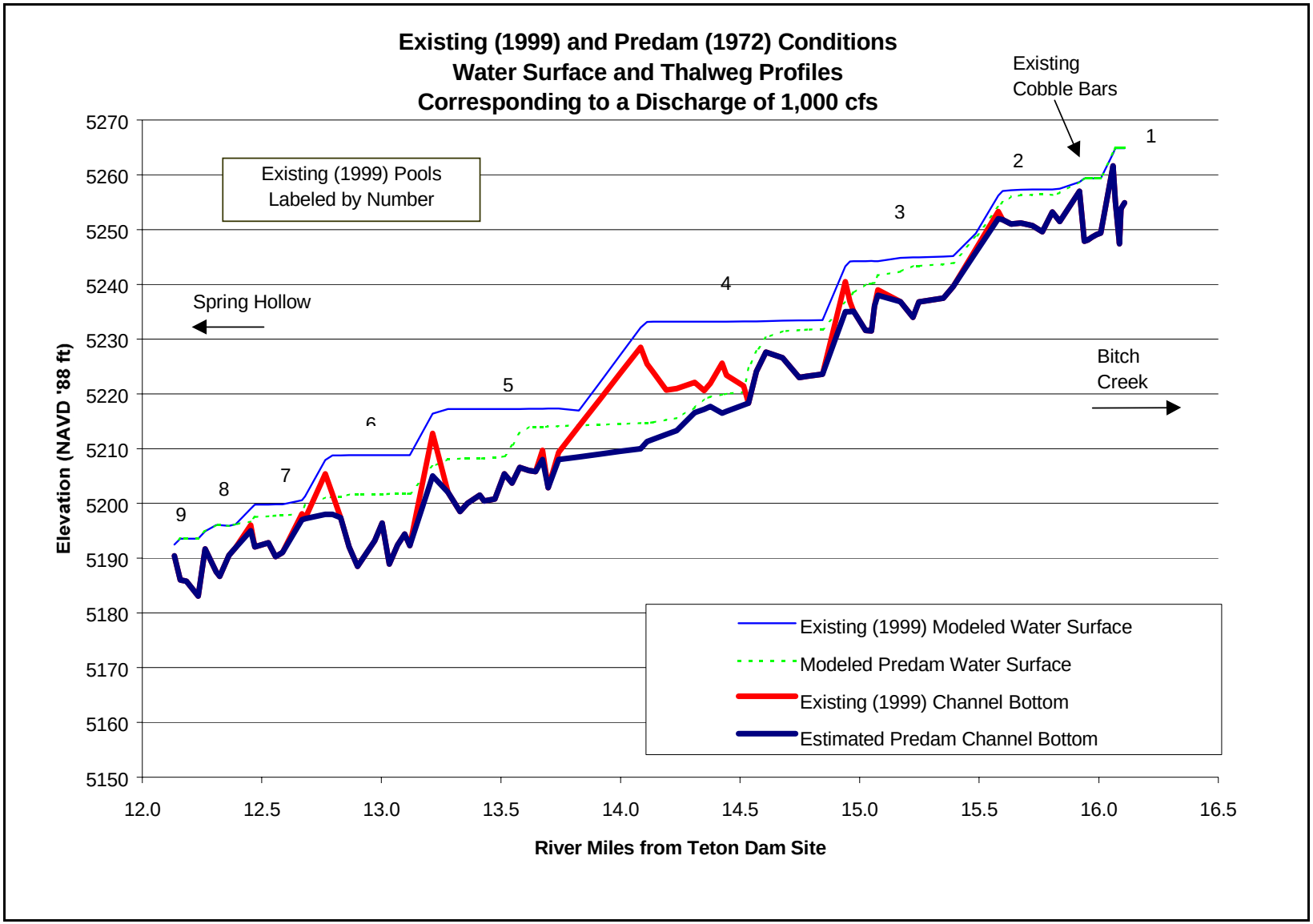

Figure 6.—Comparison of existing (1999) and predam (1972) water surface and thalweg profiles (RM 12.1 to 16.1).

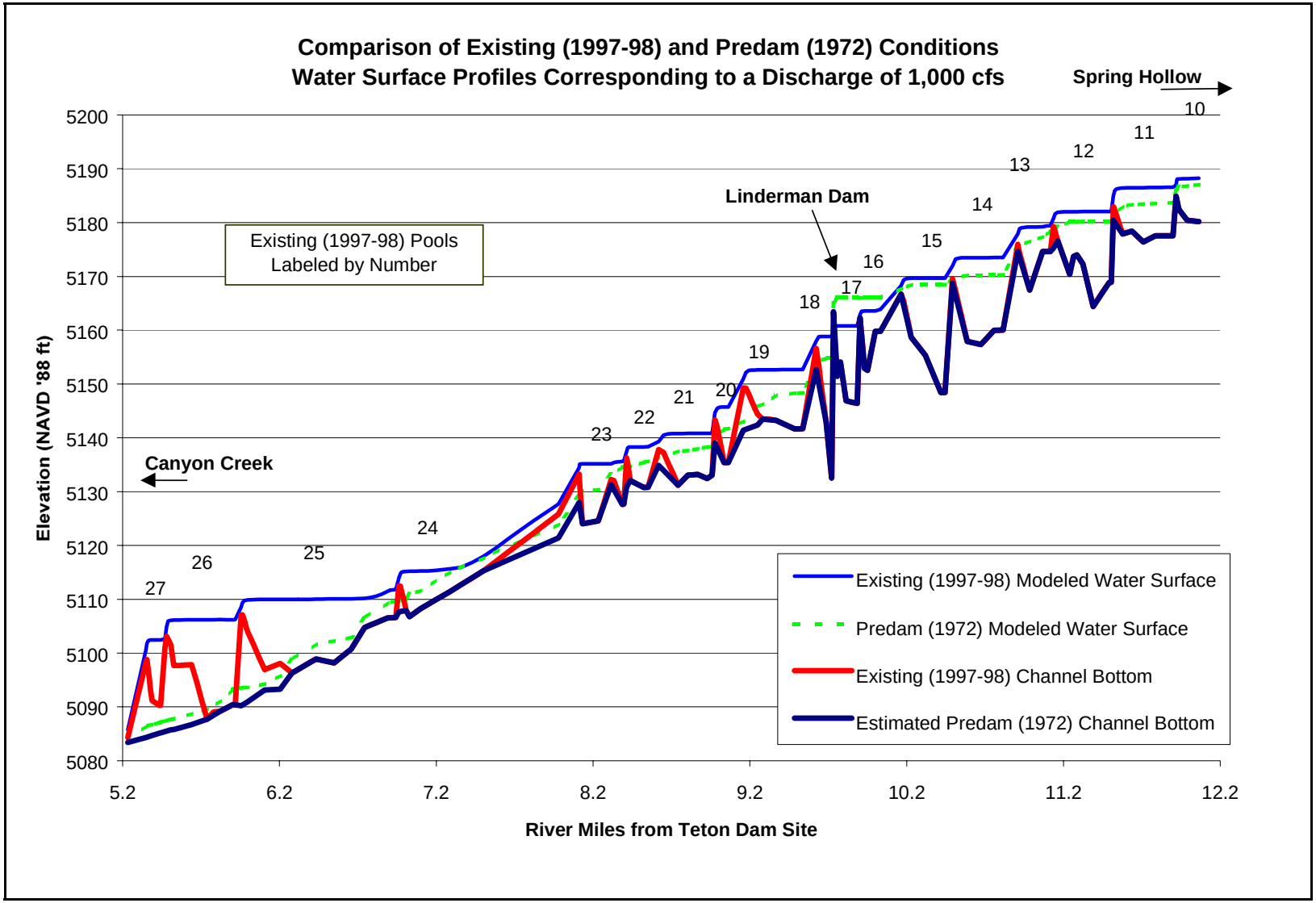

Figure 7.—Comparison of existing (1997-98) and predam (1972) water surface and thalweg profiles (RM 5 to 12.1).

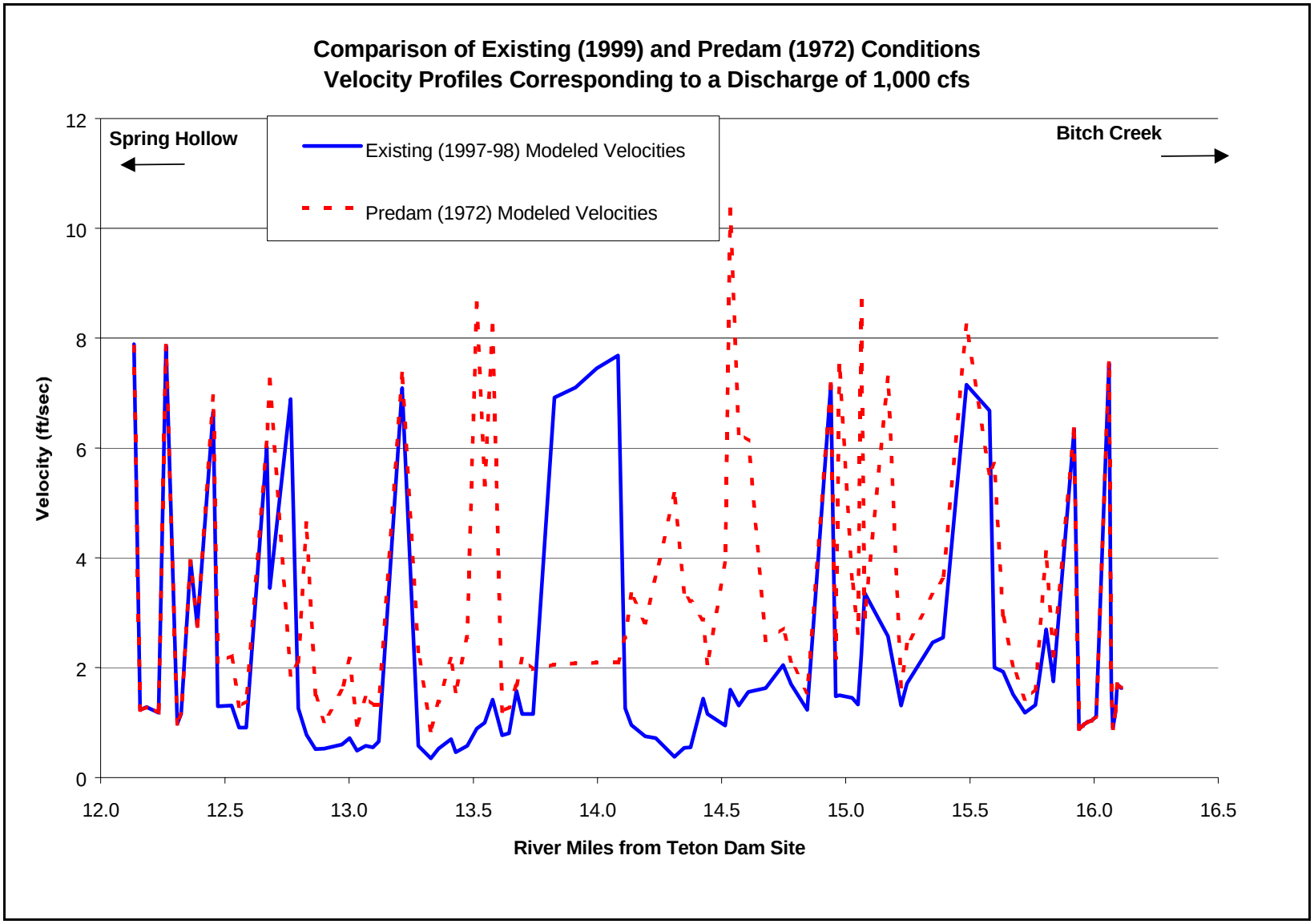

Figure 8.—Comparison of existing (1999) and predam (1972) velocity profiles (RM 12.1 to 16.1).

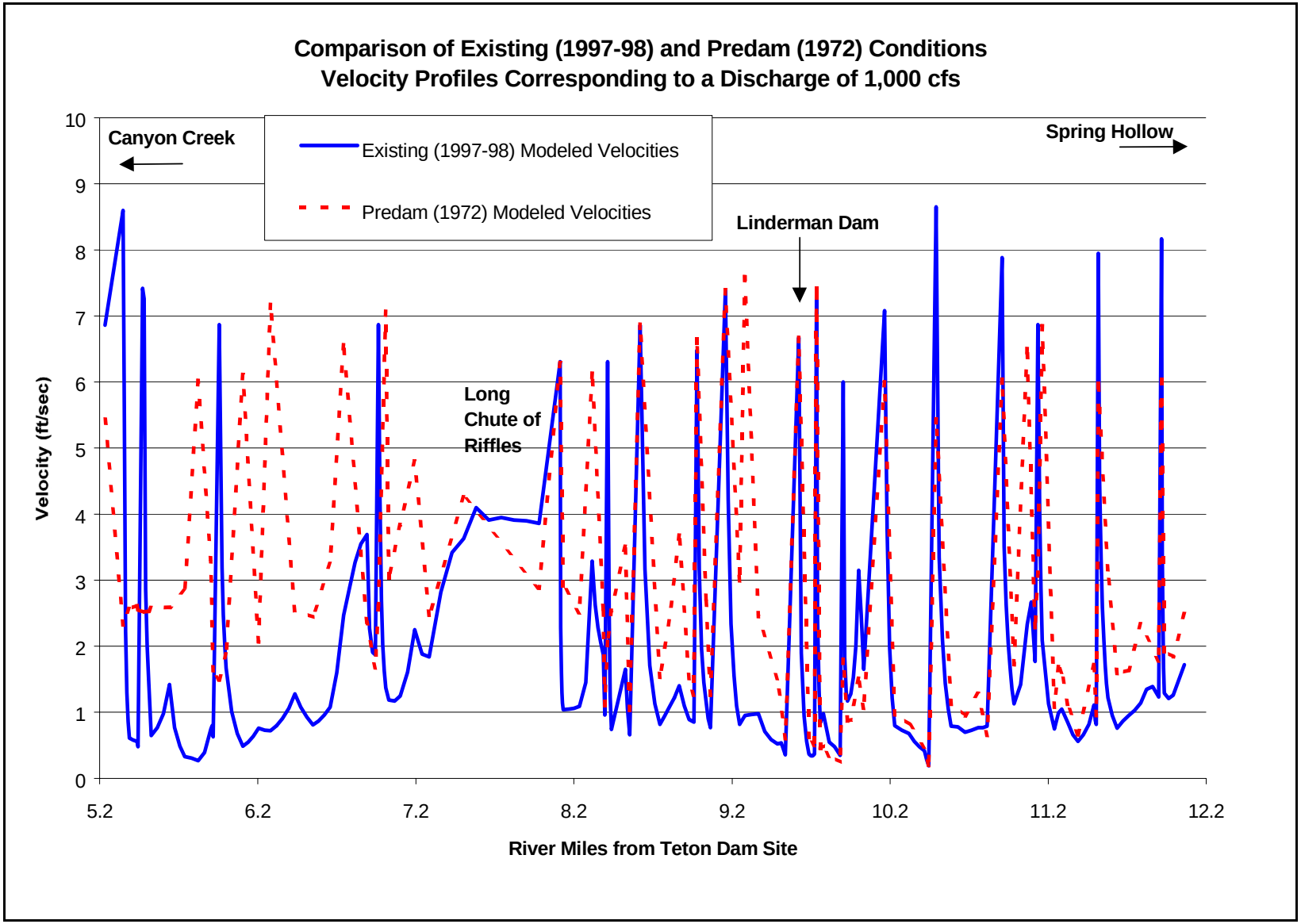

Figure 9.—Comparison of existing (1997-98) and predam (1972) velocity profiles (RM 5 to 12.1).

A summary of the hydraulic model results is presented in table 13. All of the sections have a similar top width (around 100 feet), but the riffle has significantly less flow area and higher velocities than the sections just upstream and downstream. The water surface profiles for the flood peaks versus river mile corresponding to the 2 and 100-year floods were plotted (figure H-7). All of the modeled flood peaks were also plotted at the upstream cross section (RM 4.086) to illustrate the typical scale of the right bank terrace (figure H-8). Model results show it would take a discharge greater than the 100-year flood peak to significantly inundate the high flood terrace on the right canyon wall.

Table 13.—Hydraulic properties of the Teton River at RM 4 at a discharge of 1,000 ft^3/s

River mile from Teton Dam site	Mean velocity (ft/s)	Maximum depth (ft)	Flow area (ft^2)	Top width (ft)
4.086	2.0	8	503	108
4.057	1.9	8	534	97
4.038	5.5	2	183	109
4.001	6.5	2	156	106
3.968	2.9	5	351	118
3.938	3.5	4	283	110

The computed velocities were plotted versus river mile corresponding to the flood peaks for the 2- and 100-year floods and a typical summer discharge of 1,000 cubic feet per second (figure H-9). Velocities in this reach of river range anywhere from 1 to 10 feet per second. The velocities in this reach increase much more rapidly with increases in discharge than the velocities in the deep pools in the Spring Hollow to Canyon Creek reach.

Borrow Ponds to Just Upstream From Teton Dam Site (RM 1.5 to 0.3)

The model of the borrow ponds consists of two large ponds connected by a narrow reach of river. This model was based on 27 cross sections measured in 1997 (appendix G). The narrow channel that runs parallel to the downstream borrow pond next to the Teton Dam site was not included in the model upstream from the point where the flow from the borrow ponds enters this channel (cross sections DC1 and DC2); however, the downstream-most cross section (DC3) was included (appendix G). A Manning's roughness coefficient of 0.035 was used. The borrow pond water surface elevation of 5045.8 feet (from the 1997 survey data) was used to satisfy the downstream boundary condition required for subcritical flow computations.

A summary of the hydraulic properties for the borrow ponds, including maximum depth, flow area, top width, and mean velocity, is presented for a typical summer discharge of 1,000 cubic feet per second (table 14). The total volume in the borrow ponds is approximately 1,000 acre-feet. Top widths range from 260 to 760 feet in the ponds. The channel connecting the ponds is approximately 100 to 150 feet wide. The water surface and channel bottom profile were plotted at a typical summer discharge of 1,000 cubic feet per second (figure H-10).

Table 14.—Hydraulic properties of the borrow ponds for a discharge of 1,000 ft^3/s

River mile from Teton Dam site	Mean velocity (ft/s)		Maximum depth (ft)	Flow area (ft^2)	Top width (ft)
1.490	0.5	Upstream end of borrow ponds	13	2,035	295
1.453	0.3		17	3,746	369
1.406	0.5		11	2,232	361
1.310	0.5		10	1,873	303
1.264	0.4		16	2,793	261
1.146	0.2		18	4,665	337
1.129	0.1		27	10,071	490
1.071	0.1		28	11,799	586
0.972	0.1		29	10,169	462
0.934	0.1		31	10,287	475
0.881	0.1		34	16,385	663
0.827	0.1		35	15,908	759
0.795	0.1	End of upstream borrow pond	36	11,124	396
0.774	3.6	Constriction	4	281	109
0.746	2.3	Constriction	8	436	96
0.727	0.5	Constriction	22	1,974	166
0.702	0.1	Start of downstream borrow pond	36	8,508	336
0.650	0.1		41	10,859	367
0.601	0.1		43	11,710	381
0.547	0.1		41	10,041	370
0.495	0.1		39	9,976	379
0.454	0.2		17	4,297	372
0.434	0.5		10	1,982	331
0.394	0.2		21	4,456	283
0.376	0.2	End of downstream borrow pond	22	4,775	333
0.348	0.6	Entrance to diversion channel	20	1,745	171
0.320	0.6	Diversion channel	12	1,698	219

Travel Time of Water

Once the hydraulic model was complete, the velocities computed at each of the cross sections were used to compute the travel time of water for predam and existing conditions (table 15).

Table 15.—Estimated travel times of water for existing and predam conditions at 1,000 ft^3/s

		Travel times of water at 1,000 ft^3/s (hrs)	
River mile from Teton Dam site	Teton River reach	Existing (1997-99) conditions	Predam conditions (prior to borrow ponds)
16.1 to 12.1	Bitch Creek to Spring Hollow	4.8	2.6
12.1 to 9.7	Spring Hollow to Linderman Dam	3.5	3.2
9.7 to 7.5	Linderman Dam to pool 24	2.6	1.5
7.5 to 5.0	Pool 24 to Canyon Creek	3.3	1.1
5.0 to 1.5	Canyon Creek to borrow ponds	1.6	1.4
1.5 to dam site	Borrow ponds to Teton Dam site	13.2	0.6
	CUMULATIVE:	29.0 hours	10.5 hours

The travel time from one cross section to the next was computed by dividing half the distance between the cross sections by the upstream cross-section velocity, dividing the other half of the distance by the downstream cross-section velocity, and then adding the two travel times together. For the predam conditions through the borrow ponds, it was assumed the borrow ponds had not yet been constructed, and an average velocity of 3.7 feet per second from the reach at RM 4.0 was used from Canyon Creek all the way to the dam site. The estimated travel times through Teton River at 1,000 cubic feet per second from Bitch Creek to the dam site were plotted (figure 10).

Travel time through the rapids is very fast, as expected, and travel time through the pools depends on both the length and depth of the pool. The deeper or longer the pool, the greater the travel time. The travel time through the Bitch Creek to Canyon Creek reach has increased the most between pool 24 and the confluence with Canyon Creek, where deep pools exist that did not exist prior to the 1976 landslides. The borrow ponds have increased the travel time through the last 1.5 miles upstream from the dam site by a maximum of 12.6 hours. However, the actual increase may have been less. This is because the hydraulic model did not include the river channel that can bypass flow around the downstream borrow pond. Further, because the model is one-dimensional, any potential eddy or density currents in the borrow ponds were ignored. Eddy or density currents in the borrow ponds would decrease the effective flow area through the ponds and increase flow velocity, which, in turn, would decrease travel time.

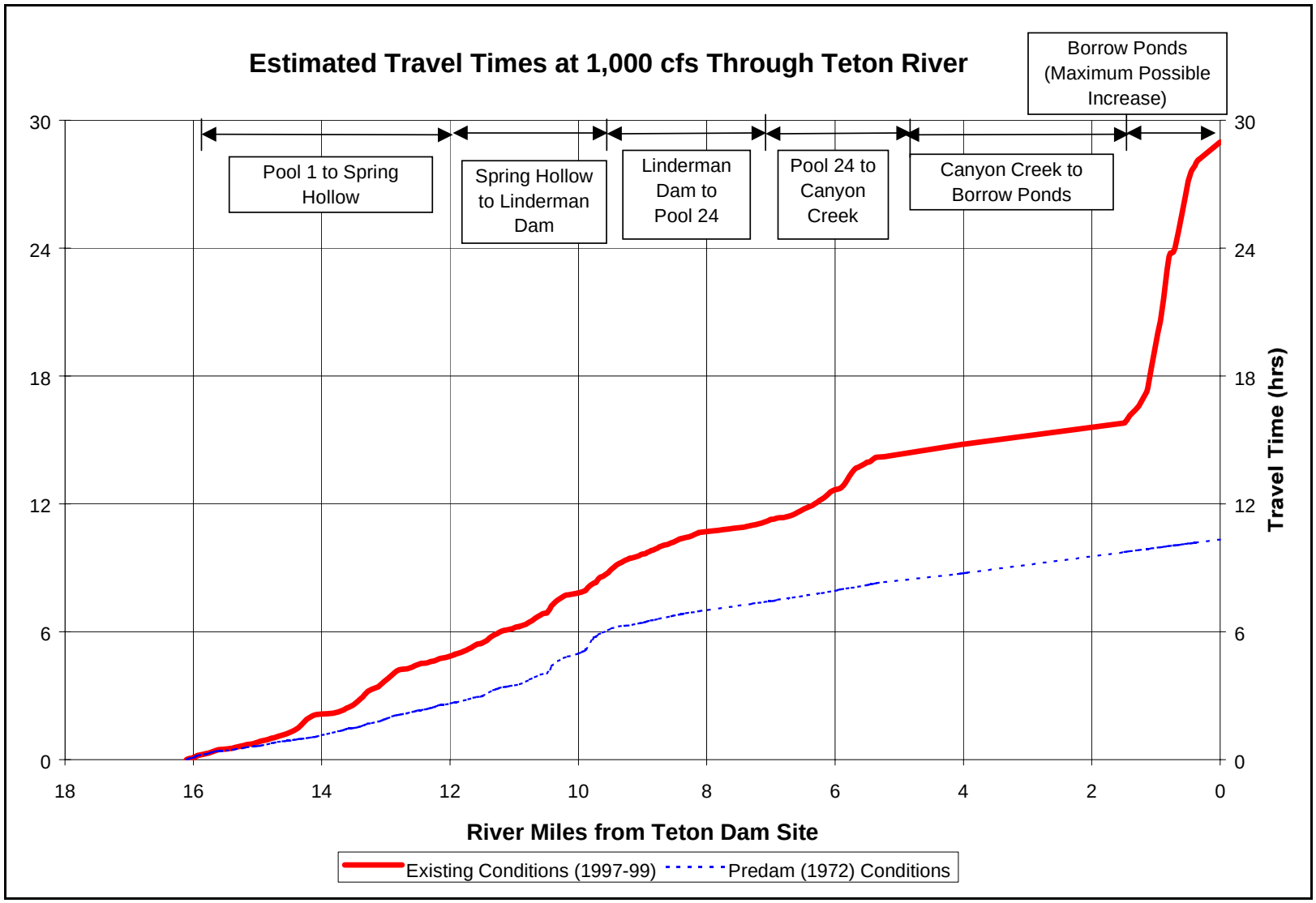

Figure 10.—Estimated water travel times corresponding to a typical summer discharge of 1,000 ft^3/s for existing (1997-99) and predam (1972) conditions in the former Teton Reservoir area.

Water Temperature

Increased temperature is postulated to result from the increased travel time, and shallow, lower velocity, larger surface area pools resulting from the many small landslides induced by inundation and dam failure that are partially blocking flow. Temperature data collection and analysis to determine likely increase in summer temperatures due to increased travel times in pools was performed during the summer of 1998 (Bowser, 1999) (figure 11). The construction and subsequent failure of Teton Dam has likely increased summer river water temperatures by 1 to 2 degrees F. Temperatures have increased because flows today move slower through the river pools enlarged by 1976 landslides and through the borrow ponds excavated for the construction of Teton Dam. The loss of riparian trees, especially in the reach downstream of Canyon Creek, also would have contributed to increased river temperatures. Suitable temperatures probably still exist in the deeper portions of the borrow ponds and river pools upstream of Canyon Creek. Most of the temperature gain occurs along the reach of river between pool 24 (7 ½ miles upstream of Teton Dam) downstream to the confluence with Canyon Creek, and in the borrow ponds.

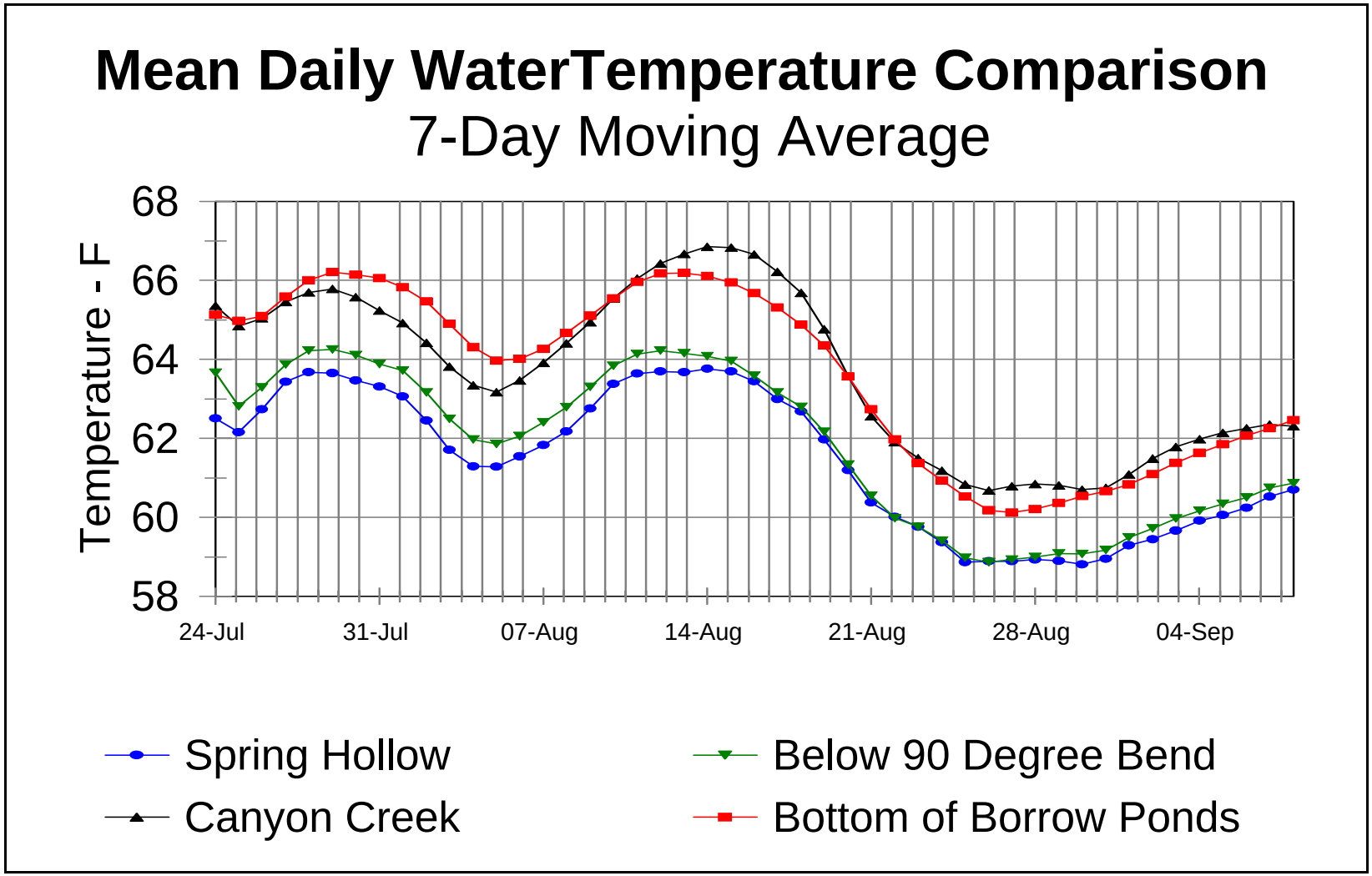

Figure 11.—Comparison of mean daily water temperatures collected in the Teton River (July 24, 1998, to September 9, 1998) at the locations of Spring Hollow, Canyon Creek, just downstream from a large bend in pool 24, and at the downstream end of the borrow ponds (Bowser, 1999).

Section 6

Major Findings and Conclusions

The Teton River canyon was affected by landslides that were caused by the inundation of Teton Reservoir and the subsequent failure of Teton Dam in 1976. Prominent landslide scars and debris fans are now common features along the Teton River canyon for nearly 17 river miles upstream from the Teton Dam site. The upstream extent of the canyon affected by the landslides is approximately 1 mile downstream from the confluence with Bitch Creek. The most significant impacts on the Teton River channel occurred in an 11-mile reach stretching from the upstream end (just downstream from Bitch Creek) downstream to the confluence with Canyon Creek.

Landslide Activity and Material

Landslide activity has been an ongoing natural geomorphic process in the Teton River canyon ever since the placement of the Huckleberry Ridge tuff and uplift of the Rexburg Bench. Landslide activity in the reservoir area started with the filling of the reservoir (Reclamation, 1976). The June 5, 1976, dam failure activated more than 200 landslides along the reservoir rim, due to the filling and the rapid drawdown of the reservoir. Approximately 1,460 acres of canyon slopes were submerged by the reservoir, and 34 percent (500 acres) failed. Approximately 3.6 million cubic feet of material moved downslope to the canyon floor, with some reaching and blocking the river. While a large amount of landslide material reached the valley floor, much of the debris remained on the lower portion of the slopes. Most of the landslides were shallow surface slumps, earth flows, debris flows, and rockfall. The thickness of the landslide debris ranged from less than 5 feet to about 25 feet.

Particle size evaluation of landslide material was completed during the 1998 field investigations along the Teton River, but should be considered preliminarily due to the small data sample. The size of the landslide material on the valley floor and lower portion of the slopes ranges from silt to boulders greater than 10 feet across. Most of the material in the landslides consists of rock fragments from 3 inches to 3 feet in diameter. This is consistent with particle size data estimated for the material on the predam reservoir slopes.

Landslides in the Teton River Canyon are an integral part of the canyon evolution. The construction and failure of the Teton Dam have rapidly accelerated those processes in the portion of the river canyon below the high elevation of the former reservoir. The 1976 landslides also significantly reduced the volume of source material available (below the former reservoir level) for future landslides. Therefore, the probability and quantity of future landslides (initiated below the elevation inundated by the former reservoir) have been significantly reduced over the next several centuries to thousands of years.

The 1976 landslides removed material from the lower canyon slopes which could tend to make the upper canyon slopes less stable. However, there is no evidence (through September 1999) that large landslides have occurred in the upper canyon slopes in the last two decades since the failure of Teton Dam. Although the upper canyon slopes have been relatively stable during the last two decades, the probability of future localized landslides on the upper canyon slopes (initiated at elevations above the former reservoir level) may have increased because of material removed from the lower canyon slopes.

Rapids and Pool Formation

Within the study reach from Bitch Creek to Teton Dam, the Teton River canyon is narrowest at the upstream end and tends to become progressively wider in the downstream direction. As the canyon widens out, terraces along both banks of the river widen out also. Upstream from the confluence with Canyon Creek, the Teton River canyon was narrow enough that the 1976 landslide debris fans typically reached the river channel. These debris fans formed new rapids in some locations and enlarged pre-existing riffles in other locations. The pre-existing riffles were formed by landslides that occurred centuries ago through natural geologic processes. Resulting from the failure of Teton Dam in 1976, 27 rapids or riffles and pools have persisted in the reach upstream from Canyon Creek (17 rapids and 1 riffle between Canyon Creek (RM 5) and Spring Hollow (RM 12.1) and 7 rapids and 2 rapid and riffle combinations upstream from Spring Hollow). Landslides also deposited debris in river-channel pools upstream from some of these rapids. Downstream from Canyon Creek, the Teton River canyon was wide enough that the landslide debris was deposited on the surface of the adjacent river terraces and typically did not reach the river channel. Therefore, the river channel was not significantly constricted by landslides downstream from Canyon Creek, and the hydraulics are relatively the same as in predam conditions.

Landslides have been naturally creating rapids and pools in the narrowest reaches of the Teton River canyon for thousands of years. For example, a debris flow that occurred during the last decade enlarged a major rapid and pool in the narrow reach between Badger Creek and Bitch Creek. This reach of the river is upstream from the area inundated by Teton Reservoir. Fluvial processes have also been at work for thousands of years. All the major rapids formed by prehistoric landslides have been reduced to small rapids and riffles through a gradual reworking of the river channel over a long period of time.

In 1972, two rapids and several small riffles existed between the confluence with Bitch Creek and Spring Hollow. There were no major rapids present along the Teton River between the Teton Dam site and Spring Hollow (based on inspection of aerial photographs). However, 13 riffles and deep pools existed in the 4-mile reach downstream from Spring Hollow (RM 8.0 to RM 12.0). It is estimated that water depths in these pools ranged from 5 to 20 feet. The landslides that occurred in 1976 enlarged many of the existing riffles into rapids and, subsequently, increased pool water surface elevations by 2 to 5 feet (an increase much less than the pool depths). These deep pools measured in 1997 downstream from Spring Hollow must have been present in 1972 because they could not have been created since 1976.

When landslides naturally occurred in the wider reaches of the Teton River canyon (prior to Teton Dam), the river channel was able to move laterally around the debris fan or incise through the area of finest material, and, consequently, deep pools were not able to persist. In contrast, when landslides naturally occurred in the narrow reaches of the canyon, the river channel was completely blocked, the riverflows were forced to spill over the coarse debris, and persistent, deep pools were formed upstream.

The 1976 landslides had the greatest impact on the Teton River channel in the 2-mile reach upstream from Canyon Creek, between RM 5.3 and RM 7.4. In this reach, there is no evidence of deep pools having been present in 1972. However, there are four new major rapids and pools (24, 25, 26, and 27) in this reach today, with pool depths ranging from 8 to 19 feet. The four landslide rapids in this reach have a total drop of over 28 feet over a distance of 2.1 miles. When looking at the impact of these rapids and pools, they must be viewed in sequence. For example, the downstream-most rapid (informally known as Parkinson's Rapid) has the largest single drop

in the river (16 feet), with the exception of rapid 4. The relatively short pool that was formed behind this rapid inundates much of the next rapid upstream (informally known as Little Parkinson's Rapid). If the downstream- most rapid were removed, the next rapid upstream would have an even larger drop than the drop through the existing Parkinson's Rapid.

No large landslides occurred in the half-mile reach downstream from RM 8.0, and the river channel was left relatively unaffected by the initial filling of the reservoir and subsequent failure of Teton Dam. The reason that no large landslides occurred in this reach is likely due to the general northeast-southwest orientation of the canyon in this location. Most of the river canyon is generally oriented in an east-west direction so that the south side of the canyon (left side looking downstream) is more shaded, retains more moisture, and develops thicker soil and forest growth than the north (right) side. The north side of the canyon gets more sun and has less moisture; thus, the canyon-wall surface is typically composed of exposed bedrock. Subsequently, nearly all of the large landslides in 1976 occurred on the south side of the canyon. In the half-mile reach downstream from RM 8.0, both sides of the canyon have significant sun exposure, and there was relatively little soil development and forest growth on either side of the canyon. Consequently, the landslides that did occur in this reach were shallow, and the river channel and hydraulics were left relatively unaffected.

Linderman Dam

Linderman Dam, at the confluence with Milk Creek (RM 9.7), was partially removed prior to the construction of Teton Dam and Reservoir. The dam still has a horizontal concrete beam that extends across a portion of the river at about the level of the water surface (photograph A-32). At low flow, the water surface is below the bottom edge of the concrete beam, while the beam is at least partially inundated at higher flows. Even though the beam may cover a portion of the water surface at higher flows, the water velocities under the beam are still high, which could create a dangerous undercurrent for boaters. There are also four vertical pipes, evenly spaced across most of the dam's crest, that protrude a few feet out of the water. Although the hydraulic drop across Linderman Dam is now only about 2 feet (compared to a 10-foot drop in 1972), the deteriorating condition of the dam (some eroded concrete and exposed metal pipes), the concrete beam that extends across a portion of the river, and the four vertical pipes protruding from the dam's crest pose a safety hazard to boaters and anglers.

Travel Time of Water

The travel time of water flowing through the Teton River canyon from the confluence with Bitch Creek to the confluence with Canyon Creek has increased as a result of the landslide debris fans forming rapids and long, slow-velocity pools in the river channel. At a typical July flow of 1,000 cubic feet per second, the travel time of water has increased from predam conditions by about 6 hours (from 8 to 14 hours). Part of this increase is due to the formation of pool 4, which has a much higher water surface and deeper depths than in 1972. The other part of this increase is mainly due to the four new large rapids between RM 5.3 and RM 7.4. Travel time of water has not changed in the reach between Canyon Creek and the borrow ponds (RM 1.5 to 5.0).

Water travel times may have significantly increased through the two large borrow ponds near the dam (RM 0.4 to 1.5), but the magnitude is not precisely known. The two borrow ponds combined are just over 1 mile in length, contain a total water volume of 1.6 million cubic yards (1,000 acre-feet), and potentially increase water travel times by up to 12.5 hours. However, flow

patterns through the borrow ponds are complex, due to the presence of a side channel which can bypass flow around the lower borrow pond and the potential for horizontal eddy currents, density currents, and vertical recirculating zones within each borrow pond. The slow moving, or nearly stagnant, water near the borrow pond surface would undoubtably be warm during the summer months, but the warm surface water may not necessarily mix with the inflowing river water (which may form a density current) and may not result in a substantial increase in water travel time.

Water Temperature

The construction and subsequent failure of Teton Dam has likely increased summer river water temperatures by 1 to 2 degrees F. Temperatures have increased because flows today move slower through the river pools enlarged by 1976 landslides and through the borrow ponds excavated for the construction of Teton Dam. The loss of riparian trees, especially in the reach downstream of Canyon Creek, also would have contributed to increased river temperatures. Suitable temperatures probably still exist in the deeper portions of the borrow ponds and river pools upstream of Canyon Creek. Most of the temperature gain occurs along the reach of river between pool 24 (7 ½ miles upstream of Teton Dam) downstream to the confluence with Canyon Creek, and in the borrow ponds.

In areas where the water temperature may have increased, it seems likely that fish requiring cooler water temperatures could move to deeper depths in pools as needed during the warmer period of the diurnal cycle. This would suggest that the "lifestyle" of native fish may be affected by forcing them to alter their movement patterns to satisfy any need for cooler water temperatures during mid- to late-afternoon. If however, the water temperature increase has occurred at a threshold boundary for fish, the one to two degree increase, along with other water quality and/or biological stressors, may actually be affecting fish mortality, forcing them to seek other habitat.

River Bed Material

An increase in water travel time tends to also increase the sediment trap efficiency of pools. This means that finer-grained sediment particles (less than 2 millimeters; i.e., sand, silt, and clay) may settle out along the pool bottom and become part of the bed material. The change in bed-material particle size, caused by the 1976 landslides, cannot be precisely determined because there is no predam data available. However, bed-material observations and samples collected in the pools upstream from Canyon Creek can be compared with the general characteristics of the channel upstream from pool 1 and downstream from Canyon Creek, which is a gravel-bed river. The bed-material data collected is dependent on discharge, particularly recent flood events, because most of the sediment is moved during high flows. Data collected prior to a flood, or at a low discharge, may give results different from data collected after a flood.

Upstream of the former reservoir inundation area, the river channel is extremely steep and narrow. The sediment transport capacity in this reach is presumably high as a result of the river gradient, narrow widths, and high velocities. Between Bitch Creek and pool 1 (the first pool backed up by a landslide-formed rapid), the river has shallow, uniform depths and the channel bed primarily consists of 3-inch cobbles to 6-foot-diameter boulders. Pool 1 is relatively short, approximately 260 feet in length which results in a short water retention time (on the order of a few minutes). The retention times increase in the downstream direction from pool 1 to pool 3 on

the order of minutes. Pool 1 with its short retention time does not trap the majority of fine sediments (clay, silt, and sand) transported by the river system. However, pool 1 would likely act as a trap for gravel and cobbles. Maximum channel depths measured at each cross section in this pool range between 10 and 18 feet. The fact that pool 1 still has significant depths after 23 years since the dam failure and the fact that the majority of the riverbed sediment observed upstream of pool 1 is boulders suggest that the gravel and cobble load of the Teton River is small.

In pools 1-3, the majority of the pools are shallow in depth and the retention times in these pools are short. The only exception is a few areas in pool 3 where depths are greater, but because the channel width also is narrow (half of the typical river channel width), the velocities are high and the retention times are short. Pool 4, approximately 4,020 feet in length, is the longest of the nine pools in the Bitch Creek to Spring Hollow reach and has the longest retention time of over an hour. The majority of the pool has a sand-covered channel bottom. Rippled sand is evident in the downstream half of the pool which indicates small velocities. The majority of sediment downstream of pool 4 to Spring Hollow appears to be silt and clay overlaying the predam riverbed or landslide debris.

On the basis of sediments observed along the channel bed, measured pool depths and channel widths, and computed water velocities and travel times, pools 1-3 appear to be near the maximum storage capacity for sand, while pool 4 is in the process of reaching this stage. Pool 4 has been trapping nearly all of the sand supplied from upstream. Eventually, pool 4 will fill in to a maximum storage capacity and sand-sized sediments will be further transported downstream. Pools with long retention times greater than an hour, such as pool 5, will also begin to fill in with fine sediments. This process to fill pool 4 has taken over 20 years, and can be expected to take near this amount to fill pool 5 and, subsequently, to fill pool 6. Eventually, over hundreds of years, the river will try to come to a stable balance where the ability to transport fine sediments equals the upstream sediment supply so that the net loss or gain of sediment storage from year to year is nearly zero.

On August 26, 1997, 30 bed-material samples were collected from 10 pools (pool numbers 10, 12, 14, 18, 19, 21, 23, 24, 25, and 26) between Spring Hollow and Canyon Creek. Of the 10 pools sampled, 8 of the pools (pool numbers 12, 14, 18, 19, 21, 23, 25, and 26) had at least one sample that was dominated by fine-grained sediment particles (less than 2 millimeters). Three of the pools (12, 25, and 26) had at least one sample that was dominated by silt or clay-size particles (less than 0.0625 millimeters). In relation to travel times, pools 25 and 26 have the longest travel times in this river reach, both over one hour. Pool 12 has the next largest travel time, at slightly greater than half an hour.

The sediment particles along the channel bottom of the pools in this reach are definitely finer than the bed material downstream from Canyon Creek. Since deep pools existed in the canyon between RM 8 to RM 12 in 1972, the change in sediment particle size, if any, is impossible to determine. However, four of the largest pools (4, 5, 25, and 26) were formed as a result of landslides in 1976 and occurred in a reach where deep pools were not present in 1972. Therefore, it is likely that the bed material of these pools is much finer today (dominated by sand, silt, and clay) than it was in 1972 (likely dominated by gravel, cobble, and boulder).

Canyon Creek

Canyon Creek is, by far, the largest tributary to the study reach. This creek was severely impacted by landslides caused by the dam failure, but the landslide debris has not been modified

to the same extent as landslide debris along the Teton River. Canyon Creek is narrower and has a steeper gradient, on average, than the Teton River, but the drainage basin area and discharges are much less than those on the Teton River. Although landslide debris in Canyon Creek is of similar size to debris in the Teton River, the low flows of Canyon Creek are much less capable of moving material. As a result, landslides and their impact on the river channel have been modified much less than those along the Teton River.

The debris fans and rapids formed by the 1976 landslides will eventually be eroded by river flows, but this process could take centuries. Since 1976, the finer-grained material in the debris fans has been reworked by riverflows, but the coarsest material was left behind and the rapids and pools are still present. The snowmelt runoff of 1997 produced the largest flood peak since 1976 and was approximately equal to the 100-year flood. Even this large magnitude flood was only capable of minor reworking of the debris forming each rapid. Therefore, the existing rapids are most likely too large to be eroded by a single flood, and the river will take centuries of abrasion and weathering to erode the rapids. This, of course, reflects the rates of natural processes which have been occurring for many thousands of years.

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Executive Summary

Geomorphology And River Hydraulics of The Teton River

The construction and subsequent failure of Teton Dam in 1976 changed the physical and biological characteristics of the Teton River canyon for 17 river miles (RM) upstream from the dam site. This report documents the existing physical conditions and the changes that have occurred to the geomorphology and river hydraulics in the Teton River canyon as a result of the reservoir inundation and subsequent failure of Teton Dam.

Looking downstream at the borrow ponds and the remnants of Teton Dam.

What is the project background?

The construction of the Teton Basin Project, Lower Teton Division, was authorized by Public Law 88-583 on September 7, 1964. This project would have provided supplemental irrigation water for approximately 110,000 acres in the Fremont-Madison Irrigation District, for flood control operation, and for recreation and fish and wildlife mitigation measures (Schuster and Embree, 1980). The 17-mile-long reservoir was to have a total capacity of 288,000 acre-feet and a surface area of 2,100 acres.

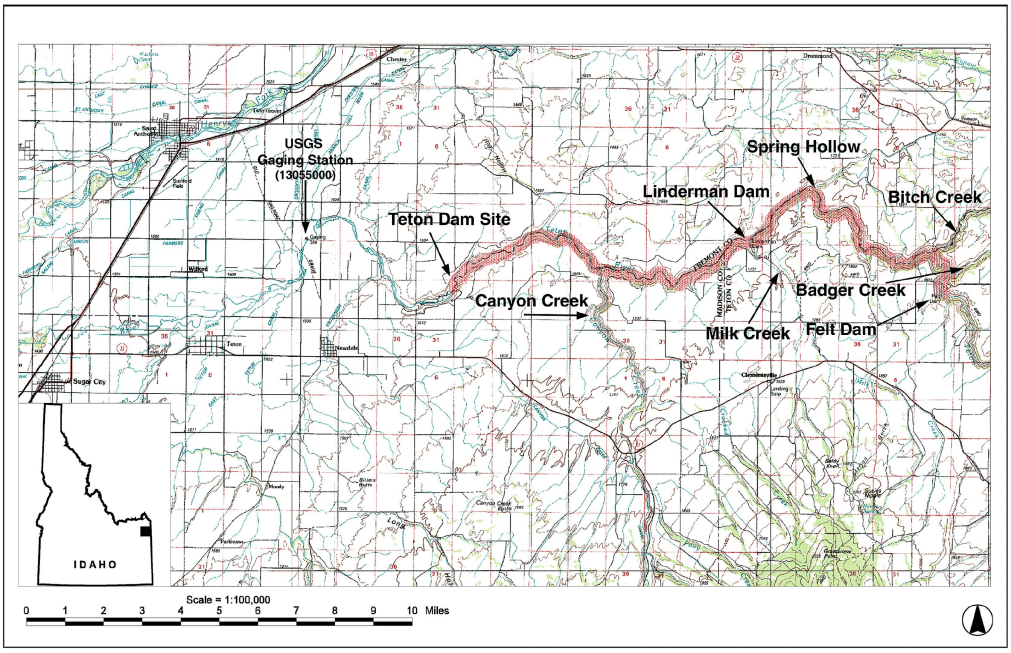
Filling of the reservoir began October 3, 1975, and continued until June 5, 1976, when Teton Dam failed (Jansen, 1980). The reservoir was at elevation 5301.7, about 272 feet deep at the dam, and 22.6 feet below the planned maximum pool elevation when piping caused the embankment to fail. Approximately 250,000 acre-feet of water and 4 million cubic yards of embankment material were sent down the river in about 6 hours (Lloyd and Watt, 1981). The destruction downstream from the dam was extensive, reaching to the upper end of American Falls Reservoir, 95 miles downstream.

In addition to the devastation caused downstream, the portion of the Teton River canyon, which was inundated by the 17-mile-long reservoir, and Canyon Creek, a tributary 5 miles upstream of the dam which was inundated for 3 miles, were also affected. The initial filling of the reservoir and subsequent rapid drawdown triggered over 200 landslides in the canyon. The original river channel and terraces have been buried in localized areas by landslide debris. Currently, the river channel contains several long, slow velocity pools that are backed up by

short, steep riffles or rapids formed from landslide debris. In addition to the reservoir-induced landslides, remnants of Linderman Dam and the submerged borrow pits upstream from Teton Dam have also impacted the slope of the river channel.

What is the purpose of studying the Teton River canyon?

As a result of the Teton Dam failure in 1976, different portions of the former reservoir inundation area have been affected in different ways. The objectives of this study are to document the current physical conditions (geologic, geomorphic, and hydraulic) of the Teton River in the former reservoir inundation area (Teton Dam site to the confluence with Bitch Creek) and changes that occurred from the filling of Teton Reservoir and subsequent failure of Teton Dam in 1976. The results from this study will provide information to assist in managing Reclamation withdrawn lands in and around the Teton River canyon upstream from the Teton Dam site. In addition, models developed from this study can be utilized as predictive tools for addressing various alternatives for modifying rapid and pool formations caused as a result of the dam failure.



Location map of study reach.

What types of data have been collected so far?

Data were collected in 1997, 1998, and 1999 along portions of the Teton River between the Teton Dam site and the Felt Dam Powerhouse, 19 river miles upstream. The data collected consist of new aerial and ground photographs, measurements of riverbed topography, water surface elevations, preliminary particle size analysis of landslide material, and bed-material particle size distributions. Additional data collected on water and air temperature, and the riparian vegetation community are described in separate reports (Bowser, 1999; Beddow, 1999).

Hydrographic data defining the water surface and channel bottom and limited topography data were collected for four reaches of river between the upstream extent of the reservoir inundation at the confluence with Bitch Creek (RM 17.2) and the Teton Dam site.

Areas of Hydrographic Data Collection

(1) The confluence with Bitch Creek to Spring Hollow (4 miles)
(2) Spring Hollow to the confluence with Canyon Creek (7 miles)
(3) A short reach at RM 4
(4) The borrow ponds (just over 1 mile)

The existing channel topography data, collected in 1997-99, were used to create a hydraulic model and a set of bathymetric maps for the Teton River pools from the confluence with Bitch Creek to the confluence with Canyon Creek and in the borrow ponds just upstream from the Teton Dam site. The maps document:

- The location of the measured data used to develop the maps
- The average daily discharge recorded at the time of the survey
- The mean measured water surface elevation of each pool during the survey
- The locations of cross sections used in the hydraulic model for this study

Particle size evaluation of landslide material was completed during the 1998 field investigations along the Teton River, but should be considered preliminary, due to the small data sample. The size of the landslide material on the valley floor and lower portion of the slopes ranges from silt to boulders greater than 10 feet across. Most of the material in the landslides consists of rock fragments from 3 inches to 3 feet across.

A previous study displayed all landslides on top of topographic contours developed in 1972 prior to the failure of Teton Dam (Magleby, 1981). To provide a new base map that represents existing topography in the canyon, a set of contour maps based on 2000 aerial photography is anticipated to be developed by the end of the year.

An example of an earthflow-type slide that occurred between Spring Hollow and Canyon Creek.

What was the extent of landslide activity in the Teton River canyon?

Landslide activity in the former reservoir area started with the filling of the reservoir (Reclamation, 1976). The June 5, 1976, dam failure activated more than 200 landslides along the reservoir rim, due to the filling and the rapid drawdown of the reservoir. Approximately 1,460 acres of canyon slopes were submerged by the reservoir, and 34 percent (500 acres) failed.

Approximately 3.6 million cubic feet of landslide debris moved downslope to the canyon floor, with some reaching and blocking the river. While a large amount of landslide debris reached the valley floor, much of the debris remained on the lower portion of the slopes.

Most of the landslides were shallow surface slumps, earth flows, debris flows, and rockfall. The thickness of the landslide debris ranged from less than 5 feet to about 25 feet normal to the slope.

Landslide activity has been an ongoing natural geomorphic process in the Teton River canyon ever since the placement of the Huckleberry Ridge tuff and uplift of the Rexburg Bench. These landslides have been naturally creating rapids and pools in the narrowest reaches of the Teton River canyon for thousands of years. For example, a debris flow that occurred during the last decade enhanced a major rapid and pool in the narrow reach between Badger Creek and Bitch Creek. This reach of the river is upstream from the area inundated by Teton Reservoir. However, fluvial processes have also been at work for thousands of years. This is why all the major rapids formed by prehistoric landslides have been reduced to small rapids and riffles.

Landslides in the Teton River Canyon are an integral part of the canyon evolution. The construction and failure of the Teton Dam have rapidly accelerated those processes in the portion of the river canyon below the high elevation of the former reservoir. The 1976 landslides also significantly reduced the volume of source material available (below the former reservoir level) for future landslides. Therefore, the probability and quantity of future landslides (initiated below the elevation inundated by the former reservoir) have been significantly reduced over the next several centuries to thousands of years.

The 1976 landslides removed material from the lower canyon slopes which could tend to make the upper canyon slopes less stable. However, there is no evidence (through September 1999) that large landslides have occurred in the upper canyon slopes in the last two decades since the failure of Teton Dam. Although the upper canyon slopes have been relatively stable during the last two decades, the probability of future localized landslides on the upper canyon slopes (initiated at elevations above the former reservoir level) may have increased because of material removed from the lower canyon slopes.

What effects did the landslides have on rapids and pool formation?

Within the study reach from Felt Dam to Teton Dam, the Teton River canyon is narrowest at the upstream end and tends to become progressively wider in the downstream direction. When

Looking upstream (in order) at pool 12, rapid 12, and pool 11, which are all slightly downstream of Spring Hollow (rapid 9).

landslides naturally occurred in the wider reaches of the Teton River canyon (prior to Teton Dam), the river channel was able to move laterally around the debris fan or incise through the area of finest material, and, consequently, deep pools were not able to persist. In contrast, when landslides occurred in the narrow reaches of the canyon, the river channel was completely blocked, the riverflows were forced to spill over the coarse debris, and persistent, deep pools were formed upstream.

In the 5-mile reach downstream from the confluence with Canyon Creek to the dam site, the landslide debris associated with the filling and rapid drawdown of Teton Reservoir landed on high terraces and typically did not reach the river channel. Therefore, the river channel and its hydraulics were not significantly affected by landslides downstream from Canyon Creek.

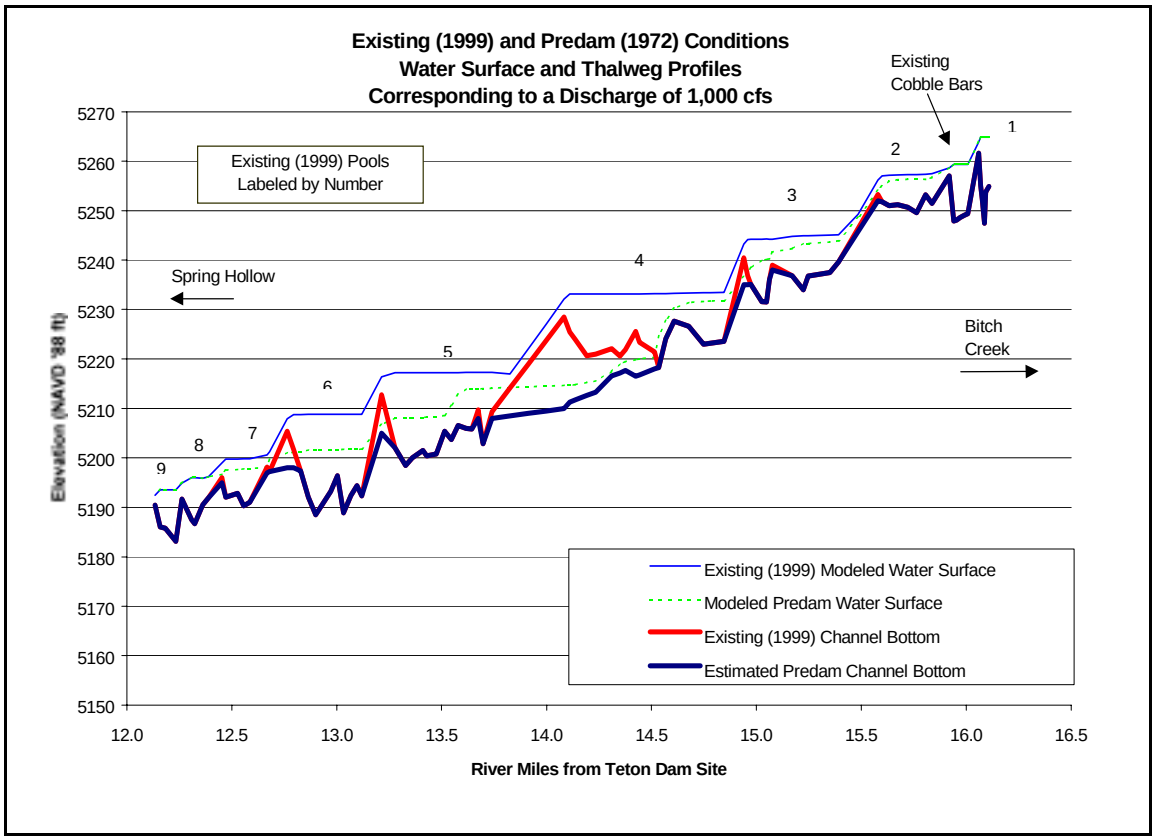
Looking upstream at a site 4 miles upstream from the dam site, where the Teton River has wide flood plains along the north side and landslide debris along the south side.

In the 12 miles upstream from the confluence with Canyon Creek, in the former reservoir area, the Teton River canyon was narrow enough that the landslide debris fans typically reached the river channel. These debris fans formed new rapids in some locations and enlarged pre-existing riffles in other locations. The pre-existing riffles were formed by landslides that occurred centuries ago through natural geologic processes.

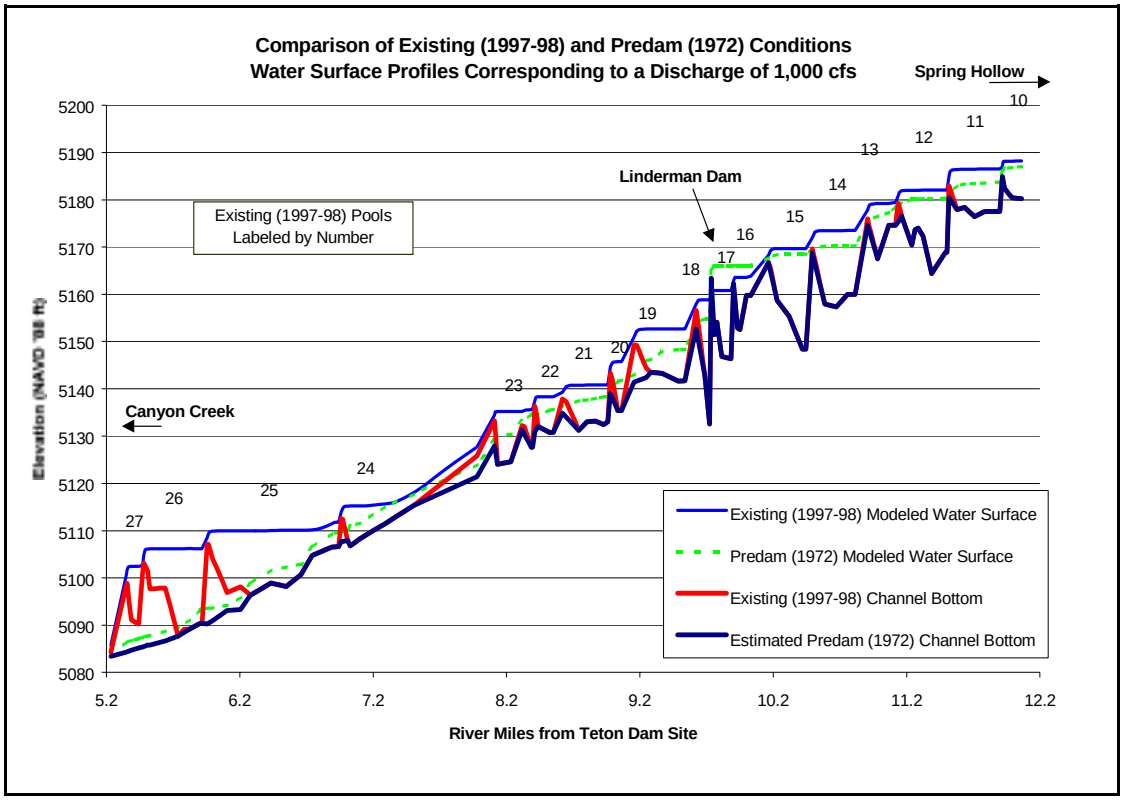
Since the failure of Teton Dam in 1976, 27 rapids and pools have persisted in the reach upstream from Canyon Creek (17 rapids and 1 riffle between pools between Canyon Creek at RM 5 and Spring Hollow at RM 12.1, and 9 rapids and 2 rapid and riffle combinations upstream from Spring Hollow). Landslides also deposited debris in river channel pools upstream from some of these rapids.

Pools are defined for this study as a portion of the river that has a water surface elevation controlled by a downstream feature (such as a riffle or rapid), has a relatively flat water surface with little or no slope, deep depths, and low velocities; and is in the subcritical flow regime. Riffles are defined for this study as a reach of river with high velocities and shallow depths that are in the critical flow regime. Rapids are defined for this study as a reach of river, typically constricted relative to upstream and downstream river widths, that passes through critical depth at the upstream end and creates a large drop in water surface elevation over a short distance. Chutes are defined for this study as a portion of the river containing a series of riffles.

In 1972, two rapids and several small riffles existed between the confluence with Bitch Creek and Spring Hollow. One of these rapids is now inundated by a new rapid formed from the dam



Bitch Creek to Spring Hollow .



Spring Hollow to Canyon Creek.

failure (rapid 1). There were no major rapids present along the Teton River between the Teton Dam site and Spring Hollow (based on inspection of aerial photographs). However, 13 riffles and deep pools existed in the 4-mile reach downstream from Spring Hollow (RM 8 to RM 12). It is estimated that water depths in these pools ranged from 5 to 20 feet. The landslides that occurred in 1976 enlarged many of the existing riffles into rapids and, subsequently, increased pool water surface elevations by 2 to 5 feet (an increase much less than the pool depths). These deep pools measured in 1997 downstream from Spring Hollow must have been present in 1972, because they could not have been created in 1976.

No large landslides occurred in the half-mile reach downstream from RM 8.0, and the river channel was left relatively unaffected by the initial filling of the reservoir and subsequent failure of Teton Dam. The reason that no large landslides occurred in this reach is likely due to the general northeast-southwest orientation of the canyon in this location. Most of the river canyon is generally oriented in an east-west direction so that the south side of the canyon (left side looking downstream) is more shaded, retains more moisture, and develops thicker soil and forest growth than the north (right) side. The north side of the canyon gets more sun and has less moisture; thus, the canyon-wall surface is typically composed of exposed bedrock. Subsequently, nearly all of the large landslides in 1976 occurred on the south side of the canyon. In the half-mile reach downstream from RM 8.0, both sides of the canyon have significant sun exposure, and there was relatively little soil development and forest growth on either side of the canyon. Consequently, the landslides that did occur in this reach were shallow, and the river channel and hydraulics were left relatively unaffected.

Where were the biggest impacts from the landslides?

In the Bitch Creek to Spring Hollow reach, the 1976 landslides had the greatest impact on a 2-mile stretch of river where 3 major rapids now exist, creating a 30.5-foot drop over 3 pools (4, 5, and 6). Pool 4 is the longest of the pools, stretching over 4,000 feet.

In the Spring Hollow to Canyon Creek reach, the 1976 landslides had the greatest impact on the Teton River channel in the 2-mile reach upstream from Canyon Creek. In 1972, there was no evidence of deep pools present. However, there are four new major rapids and pools (24, 25, 26, and 27) in this reach today, with pool depths ranging from 9 to 19 feet. The four landslide rapids in this reach have a total drop of 26 feet over a distance of 2.1 miles.

These rapids and pools must be viewed in sequence. For example, the downstream-most rapid (informally known as Parkinson's Rapid) has the largest single drop in the river in this reach

View of Parkinson's Rapid looking downstream.

(16 feet). The relatively short pool that was formed behind this rapid inundates much of the next rapid upstream (informally known as Little Parkinson's Rapid). If the downstream-most rapid were removed, the next rapid upstream would have an even larger drop than the drop through the existing Parkinson's Rapid.

What are the impacts at Linderman Dam?

Linderman Dam, at the confluence with Milk Creek (RM 9.7), still has a horizontal concrete beam that extends across a portion of the river at about the level of the water surface (see photograph A-32 in appendix A). At low flow, the water surface is below the bottom edge of the concrete beam, while the beam is at least partially inundated at higher flows. Even though the beam may cover a portion of the water surface at higher flows, the water velocities under the beam are still high, which could create a dangerous undercurrent for boaters. There are also four vertical pipes, evenly spaced across most of the dam's crest, that protrude a few feet out of the water. Although the hydraulic drop across Linderman Dam is now only about 2 feet, the deteriorating condition of the dam (some eroded concrete and exposed metal pipes), the concrete beam that extends across a portion of the river, and the four vertical pipes protruding from the dam's crest pose a safety hazard to boaters and anglers.

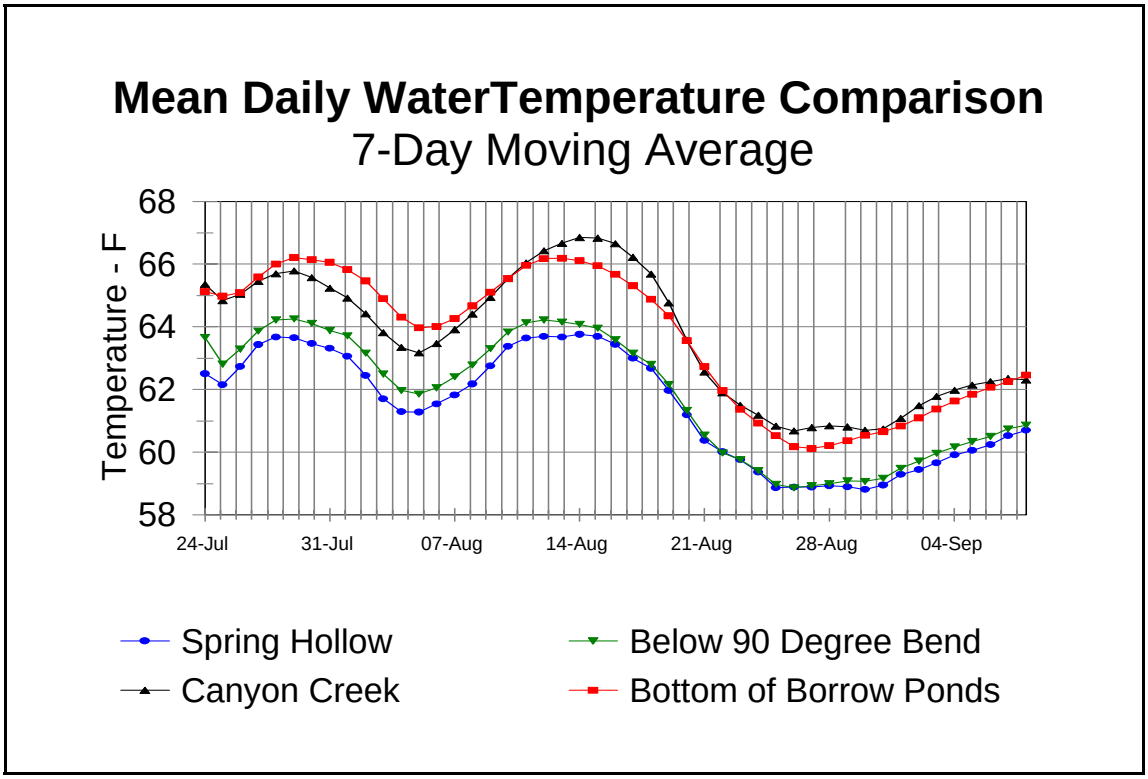
View of Linderman Dam looking upstream.

How have the new rapids affected water travel time and temperatures?

Water travel time is the amount of time needed for water to pass through a particular reach of river. The travel time of water flowing through the Teton River canyon from the confluence with Bitch Creek to the confluence with Canyon Creek has increased as a result of the landslide debris fans forming rapids and long, slow-velocity pools in the river channel. At a typical July flow of 1,000 cubic feet per second, the travel time of water has increased from predam conditions by about 6 hours (from 8 to 14 hours). Part of this increase is due to the formation of pools 4, 5, and 6, which have a much higher water surface and deeper depths than in 1972. The other part of this increase is due mainly to the four new large rapids between RM 5.3 and RM 7.4. Travel time of water has not changed in the reach between Canyon Creek and the borrow ponds (RM 1.5 to 5.0).

Water travel times may have significantly increased through the two large borrow ponds near the dam (RM 0.4 to 1.5), but the magnitude is not precisely known. The two borrow ponds combined are just over 1 mile in length, contain a total water volume of 1.6 million cubic yards (1,000 acre-feet), and potentially increase water travel times by up to 12.5 hours. However, flow patterns through the borrow ponds are complex, due to the presence of a side channel which can bypass flow around the lower borrow pond and the potential for horizontal eddy

currents, density currents, and vertical recirculating zones within each borrow pond. The slow moving, or nearly stagnant, water near the borrow pond surface would undoubtably be warm during the summer months, but the warm surface water may not necessarily mix with the inflowing river water (which may form a density current) and may not result in a substantial increase in water travel time.



Increased temperature is postulated to result from the increased travel time, and shallow, lower velocity, larger surface area pools resulting from the many small landslides induced by inundation and dam failure that are partially blocking flow. The construction and subsequent failure of Teton Dam has likely increased summer river water temperatures by 1 to 2 degrees Fahrenheit (°F). Temperatures have increased because flows today move slower through the river pools enlarged by 1976 landslides and through the borrow ponds excavated for the construction of Teton Dam. The loss of riparian trees, especially in the reach downstream of Canyon Creek, also would have contributed to increased river temperatures. Suitable temperatures for trout probably still exist in the deeper portions of the borrow ponds and river pools upstream from Canyon Creek. Most of the temperature gain occurs along the reach of river between pool 24 (7-½ miles upstream of Teton Dam) downstream to Canyon Creek and in the borrow ponds.

During the water temperature monitoring period, all of the data loggers recorded at least one or more temperatures above 60 °F. Although the 1- to 2-°F increase in water temperature appears small, the increase could be significant if the natural water temperatures needed by Teton River fish species were already near their threshold. It seems likely that fish can find cooler water temperatures at deeper depths known to exist, but not monitored in this study, as

needed during the warmer period of the diurnal cycle. This would suggest that the "lifestyle" of native fish may be affected by forcing them to seek deeper depths during mid- to late afternoon.

How has the Teton River bed material composition changed?

River bed material refers to the types of sediments found along the channel bed of a river. In the former reservoir area, the enlargement and development of the 27 pools from the dam failure has affected the river's capacity to transport sediment. The increase in water travel time found in some of the pools has increased the sediment trap efficiency in those pools. This means that finer-grained sediment particles (i.e., sand, silt, and clay) may settle out along the pool bottom and become part of the channel bed material. The change in bed-material particle size, caused by the 1976 landslides, cannot be precisely determined because there is no predam data available. However, bed-material observations and samples collected in the pools upstream from Canyon Creek were compared with the general characteristics of the channel upstream from pool 1 and downstream from Canyon Creek, which is a gravel-bed river.

Looking downstream from Felt Dam Powerhouse, located about 19 miles upstream from Teton Dam (upstream of the former reservoir area).

Upstream from the former reservoir inundation area, the river channel is extremely steep and narrow. The sediment transport capacity in this reach is presumably high, as a result of the river gradient, narrow widths, and high velocities. Between Bitch Creek and pool 1 (the first pool backed up by a landslide-formed rapid), the river has shallow, uniform depths, and the channel bed primarily consists of 3-inch to 6-foot-diameter boulders.

On the basis of sediments observed along the channel bed, measured pool depths and channel widths, and computed water travel times, pools 1-3 appear to be near the maximum storage capacity for sand, and pool 4 has been the major sediment trap along the river. Eventually, pool 4 will fill in to a maximum storage capacity, and fine-grained sediments will be further transported downstream. Because of its long travel time (over 1 hour), pool 5 will be the next major sediment trap in the river system. The process to nearly fill pool 4 has taken over 20 years and can be expected to take near this amount to fill in pool 5.

The sediment particles along the channel bottom of the pools in the Spring Hollow to Canyon Creek reach are definitely finer than the bed material downstream from Canyon Creek. Silts and clay-sized sediments have deposited along the channel bed in the longer and slower pools. The largest pools (25 and 26) were formed as a result of landslides in 1976 and occurred in a

reach (RM 5.5 to RM 6.9) where deep pools were not present in 1972. Therefore, it is likely that the bed material of these pools is much finer today (dominated by sand, silt, and clay) than it was in 1972 (likely dominated by gravel, cobble, and boulder).

Was Canyon Creek affected by the dam failure?

Canyon Creek is, by far, the largest tributary to the study reach. This creek was severely impacted by landslides caused by the dam failure, but the landslide debris has not been modified to the same extent as landslide debris along the Teton River. Canyon Creek is narrower and has a steeper gradient, on average, than the Teton River, but the drainage basin area and discharges are much less than those on the Teton River. Although landslide debris in Canyon Creek is of similar size to debris in the Teton River, the low flows of Canyon Creek are much less capable of moving material. As a result, landslides and their impact on the river channel have been modified much less than those along the Teton River.

Will the river break down the rapids in time?

The debris fans and rapids formed by the 1976 landslides will eventually be eroded by riverflows, but this process could take centuries. Since 1976, the finer-grained material in the debris fans has been reworked by riverflows, but the coarsest material was left behind, and the rapids and pools are still present. The snowmelt runoff of 1997 produced the largest flood peak since 1976 and was approximately equal to the 100-year flood. Even this large magnitude flood was only capable of minor reworking of the debris forming each rapid. Therefore, the existing rapids are most likely too large to be eroded by a single flood, and the river will take centuries of abrasion and weathering to erode the rapids. This, of course, reflects the rates of natural processes which have been occurring for many thousands of years.

A view of rapid 26, which was formed from landslide material that moved into the river from the north canyon wall.

Photograph A-1.The construction and failure of Teton Dam and Teton Reservoir in 1976 changed the physical and biological characteristics of the Teton River canyon upstream from the dam site. Today, the remnants of Teton Dam are a constant reminder of the changes that occurred, mostly from the filling and rapid drawdown of the 17-mile-long Teton Reservoir. USBR photograph by Tim Randle, 1997.

Photograph A-2.The Teton River canyon upstream of Teton Dam (located in Madison, Fremont, and Teton Counties, Idaho) is generally oriented in an east-west direction. The north-facing canyon walls support thick stands of conifers growing in thick, fine-grained soils. The south-facing canyon walls are steep, bedrock slopes that lack the well-developed soils and only support sparse stands of juniper and sage. USBR photograph by Tim Randle, 1997.

Photograph A-3. Upstream of the dam, the narrow canyon incised into the 1.2-Ma Huckleberry Ridge Tuff. The canyon becomes gradually wider in the downstream direction and is flanked by a low flood plain and higher terraces. USBR photograph by Tim Randle, 1997.

Photograph A-4.Early Holocene or late Pleistocene soil developed on colluvium is preserved along the south-facing canyon wall at this location. USBR photograph by Ralph Klinger, 1998.

Photograph A-5.During the filling and rapid drawdown of the reservoir in 1976, hundreds of landslides occurred along the canyon walls, the majority of which are located on the north-facing canyon walls. USBR photograph by Tim Randle, 1998.

Photograph A-6.View of a translational slide along the south wall of the Teton River Canyon. Note the shallow depth of the landslide and the bedrock exposed in the slide surface. The material at the base of the slide ranges from sand to boulders up to 5 feet in diameter. USBR photograph by A.C. Lockhart, July 21, 1998

Photograph A-7.View of an earthflow slide along the Teton River Canyon between Spring Hollow and Canyon Creek. Note that this slide is in a thicker colluvium and has a deep headscarp. The material in the slide ranges from silt to large boulders. USBR photograph by A.C. Lockhart, July 21, 1998.

Photograph A-8.View of a rockfall slide along the south-facing Teton River canyon wall between Spring Hollow and Canyon Creek. Note the large blocks of rock at the base of the slope. The blocks range from 2 feet to over 10 feet in diameter, with the majority ranging from 3 feet to 5 feet. USBR photograph by A.C. Lockhart, July 21, 1998.

Photograph A-9.Landslide-material particle size data was collected at seven sites in the study reach. This landslide was located between Spring Hollow and Canyon Creek along the south canyon wall. This site was used to make a random size estimate of landslide debris. The majority of the blocks are in the cobble to boulder size range (up to 3 feet in diameter). USBR photograph by A.C. Lockhart, July 21, 1998.

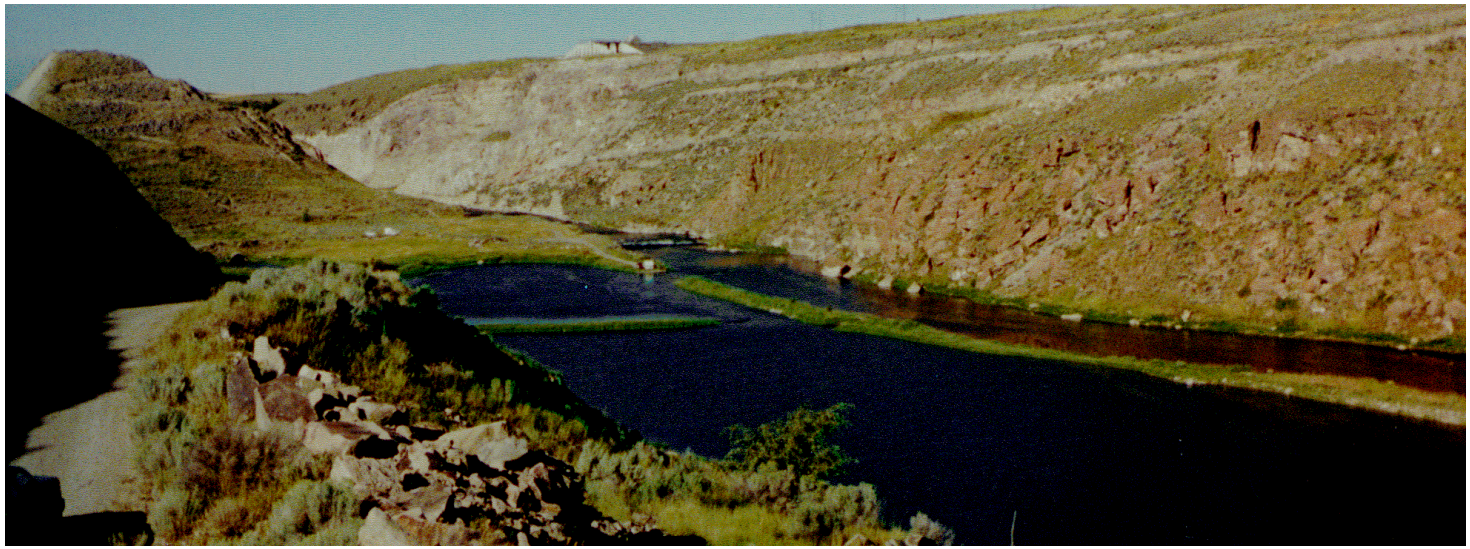
Photograph A-10.In the upper portion of the former reservoir area, the canyon is narrow and constricts the river. Landslide debris that slid into the river constricted the channel forming rapids that backed up pools. Eddies have formed where the channel expands downstream of the constrictions. USBR Photograph by Tim Randle, 1997.

Photograph A-11. In many cases, landslides occurred at the same location as previous slides, thus enlarging existing riffles or islands visible in 1972 aerial photographs prior to the construction of Teton Dam, such as this island at the mouth of Spring Hollow. USBR photograph by Tim Randle, 1997.

Photograph A-12. In this section, where the canyon is wider and the river has more room to meander, landslide debris has deflected the river channel, causing erosion of the previously stable bank. USBR photograph by Tim Randle, 1997.

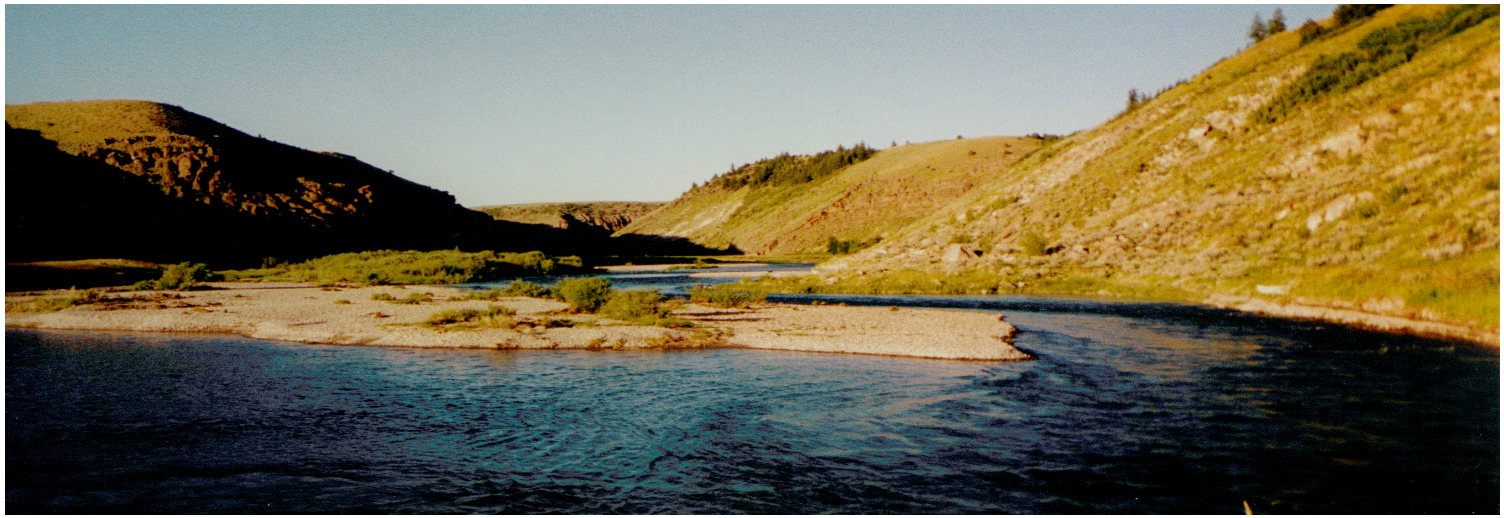
Photograph A-13. Hydrographic surveys of the channel bottom were completed along portions of the Teton River in the former reservoir area (about 15 miles upstream of the dam site) using a survey raft equipped to measure water depths. USBR photograph by Tim Randle, 1997.

Photograph A-14. A total station survey instrument was used to track and measure the horizontal and vertical position of the survey raft. USBR photograph by Jennifer Bountry, 1998.



Photograph A-15. The first survey reach (measured in 1997) was the borrow ponds, which extend for 1½ miles upstream of Teton Dam. The borrow ponds consist of two ponds which were excavated during the construction of Teton Dam. USBR photograph by Tim Randle, 1997.

Photograph A-16. A river channel along the right canyon wall parallels the borrow ponds and was constructed to bypass flows around the downstream pond. USBR photograph by Tim Randle, 1997.



Photograph A-17. Looking upstream of the borrow ponds, the river naturally meanders between stream terraces and gravel bars. USBR photograph by Tim Randle, 1997.

Photograph A-18. Four miles upstream of the dam site, the Teton River has wide flood plains along the north side (river right), landslide debris along the south side (river left), and flow that alternates between shallow pools and fast moving riffles. View is looking upstream. USBR photograph by Jennifer Bountry, 1998.

Photograph A-19. Along this reach, 4 miles upstream of the dam site, the river channel is being deflected by landslide material on the left bank and has begun to erode the right bank. USBR photograph by Jennifer Bountry, 1998.

Photograph A-20. Just below Canyon Creek (about 4½ river miles upstream of the dam site), a pumping plant is located on the right bank of the river, and an irrigation pipeline crosses the river. USBR photograph by Tim Randle, 1997.

Photograph A-21. In the river reach between the confluence with Canyon Creek and the confluence with Bitch Creek (12 river miles of the former reservoir area), 27 pools and rapids were formed or enlarged by landslides from the filling and rapid drawdown of the Teton Reservoir in 1976. This is the largest rapid (rapid 27) located just upstream of Canyon Creek. This rapid is formed of landslide debris that came from the left canyon wall. The vertical elevation drop through this rapid is approximately 16 feet. USBR photograph by Tim Randle, 1997.

Photograph A-22. The particle size of landslide material forming rapid 27 varies from cobbles to large boulders. Much of the finer-grained material has been transported downstream. USBR photograph by Tim Randle, 1997.

Photograph A-23. Along the right bank of rapid 27, older sage covered colluvium. USBR photograph by Ralph Klinger, 1998.

Photograph A-24. A size count estimate of landslide material was made on the left bank of rapid 27. Two counts were made in a 10,000 -square-foot grid at this site. USBR photograph by A.C. Lockhart, July 22, 1998.

Photograph A-25. Existing pools, riffles, and rapids are numbered from the upstream end of the former reservoir area (mouth of Bitch Creek) to the dam site in ascending order. Pool 27, formed by rapid 27, is a short (500 feet) and fairly wide (250 feet) pool. This view is looking downstream. USBR photograph by Tim Randle, 1998.

Photograph A-26. View of rockfall on the north canyon wall upstream of rapid 27. The majority of the material ranges in size from cobbles (3 inches to 12 inches) to small boulders (1.0 feet to 3 feet). The large blocks of rock are 2 feet to 5 feet in diameter. USBR photograph by A.C. Lockhart, July 22, 1998.

Photograph A-27. Rapid 26 was formed from landslide material that moved into the river from the north canyon wall. Over time, the river has cut through the slide debris, transporting fine-grained material downstream and leaving large blocks of rock that back up pool 26. USBR photograph by A.C. Lockhart, July 22, 1998.

Photograph A-28. The drop through rapid 25 was measured to be over 3½ feet. USBR photograph by Tim Randle, 1998.

Photograph A-29. Pool 23 starts just downstream of a long series of riffles and is approximately 2,850 feet long. Pool 23 marks the beginning of the nearly 2-mile-long reach with the most change. This view is looking upstream of a 90-degree bend in the river. USBR photograph by Tim Randle, 1998.

Photograph A-30. The landslide headscarp on the left canyon wall and debris that formed rapid 22. USBR photograph by Tim Randle, 1998.

Photograph A-31. Looking upstream at Linderman Dam, located about 10 miles upstream of Teton Dam at the confluence with Milk Creek. This dam was in operation in 1972, creating a 10-foot drop in water surface and backing up a pool of water over 3,600 feet long. During the construction of Teton Dam, Linderman Dam was partially removed, leaving remnants that create only a 2-foot drop in water surface. USBR photograph by Tim Randle, 1998.

Photograph A-32. Looking downstream at Linderman Dam. A portion of the dam has a dangerous underflow current not visible to boaters at higher flows. In addition, pieces of the old structure stick vertically out of the water in the main channel flow. USBR photograph by Tim Randle, 1997.

Photograph A-33. In pool 15, about 10 river miles upstream of Teton Dam, a drowned juniper tree provides evidence for the extent of inundation in this pool caused by landslides downstream. USBR photograph by Ralph Klinger, 1998.

Photograph A-34. Stump of drowned tree in growth position on inundated terrace in pool 15. USBR photograph by Ralph Klinger, 1998.

Photograph A-35. Landslide on left canyon wall at rapid 12. Note the extent of modification to the slide debris forming the rapid. USBR photograph by Ralph Klinger, 1998.

Photograph A-36. Island in pool 12 formed of slide debris derived from the left canyon wall. USBR photograph by Ralph Klinger, 1998.

Photograph A-37. Rapid 11, about 11½ river miles upstream of Teton Dam, has a drop of 5 feet in water surface elevation. A riffle existed at this location prior to the dam failure and was enlarged by the 1976 landslides. USBR photograph by Tim Randle, 1998.

Photograph A-38. View of landslides on the south canyon wall below Spring Hollow. The landslides are slumps in the colluvium. Note the larger rock on the headscarps. Also note that only a small percentage of the slide material reached the river. USBR photograph by A.C. Lockhart, July 21, 1998.

Photograph A-39. Spring Hollow is a boat launch site about 12 river miles upstream from Teton Dam. A midchannel sand bar was formed, in part, from landslide debris. USBR photograph by Tim Randle, 1997.

Photograph A-40. Looking upstream from the mouth of Bitch Creek, about 17 river miles upstream of Teton Dam, at its confluence with the Teton River. Just downstream of this confluence marks the upstream extent of the former reservoir inundation area. USBR photograph by Tim Randle, 1998.

Photograph A-41. A large debris flow between Badger and Bitch Creeks on the left canyon wall in 1997. This debris flow is evidence that landslides are a naturally occurring process in the Teton River Canyon. USBR photograph by Tim Randle, 1997.

Photograph A-42. This photograph shows the debris and rapid resulting from the debris flow shown in photograph A-41. USBR photograph by Tim Randle, 1998.

Photograph A-43. Closeup view of the debris flow shown in photographs A-41 and A-42. Note the size of debris compared to people standing on rocks. USBR photograph by A.C. Lockhart, July 19, 1998.

Photograph A-44. USGS gage site (Station 13054200) between Badger and Bitch Creeks. USBR photograph by Jennifer Bountry, 1998.

Photograph A-45. Looking downstream from Felt Dam Powerhouse, located about 19 miles upstream of Teton Dam. USBR photograph by Jennifer Bountry, 1998.

Photograph A-46. Looking upstream from Felt Dam Powerhouse. This is the upstream end of the study reach. USBR photograph by Jennifer Bountry, 1998.

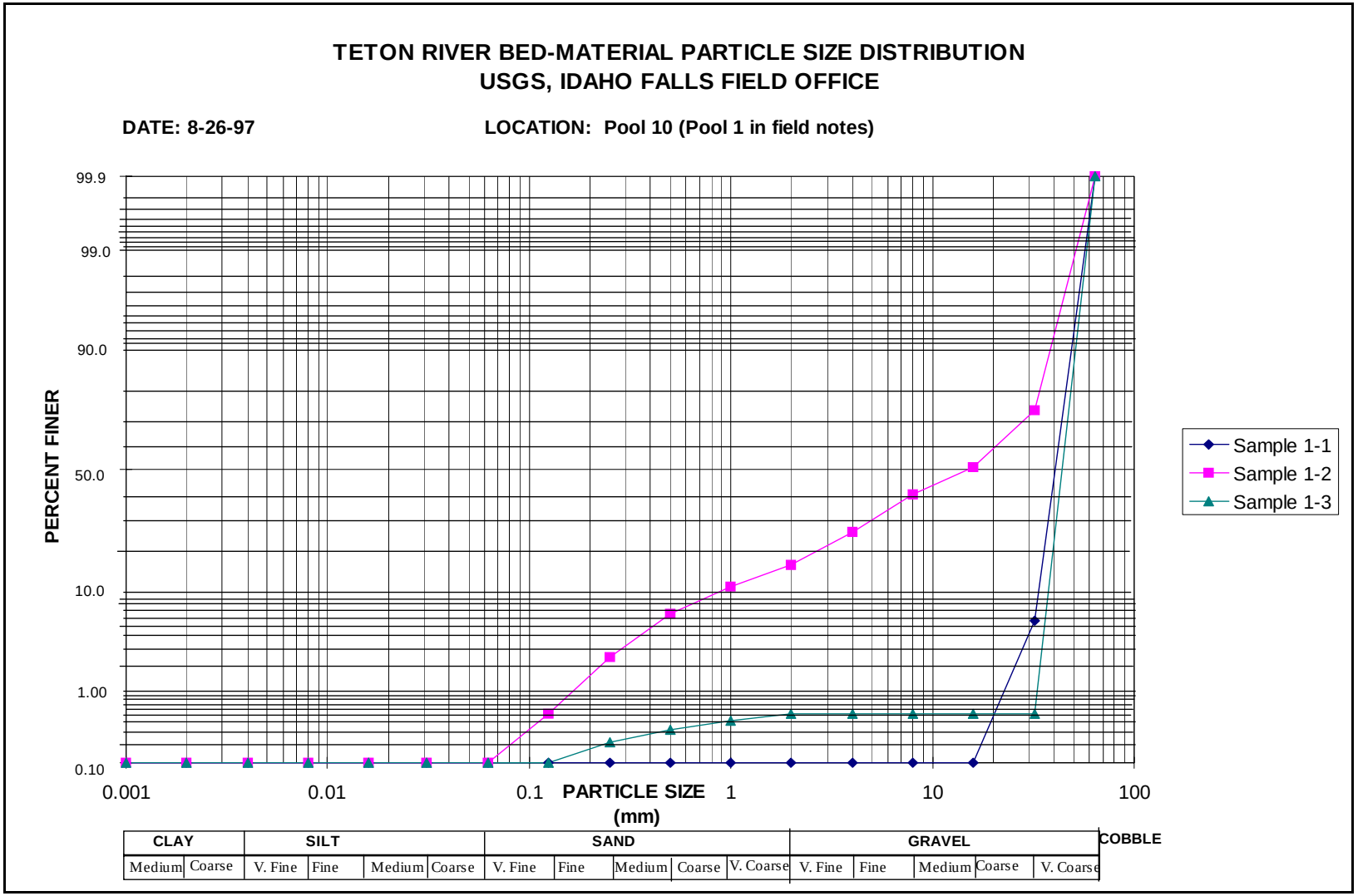


Figure B-1.-Particle size distribution plot corresponding to bed-material samples in Pool 10.

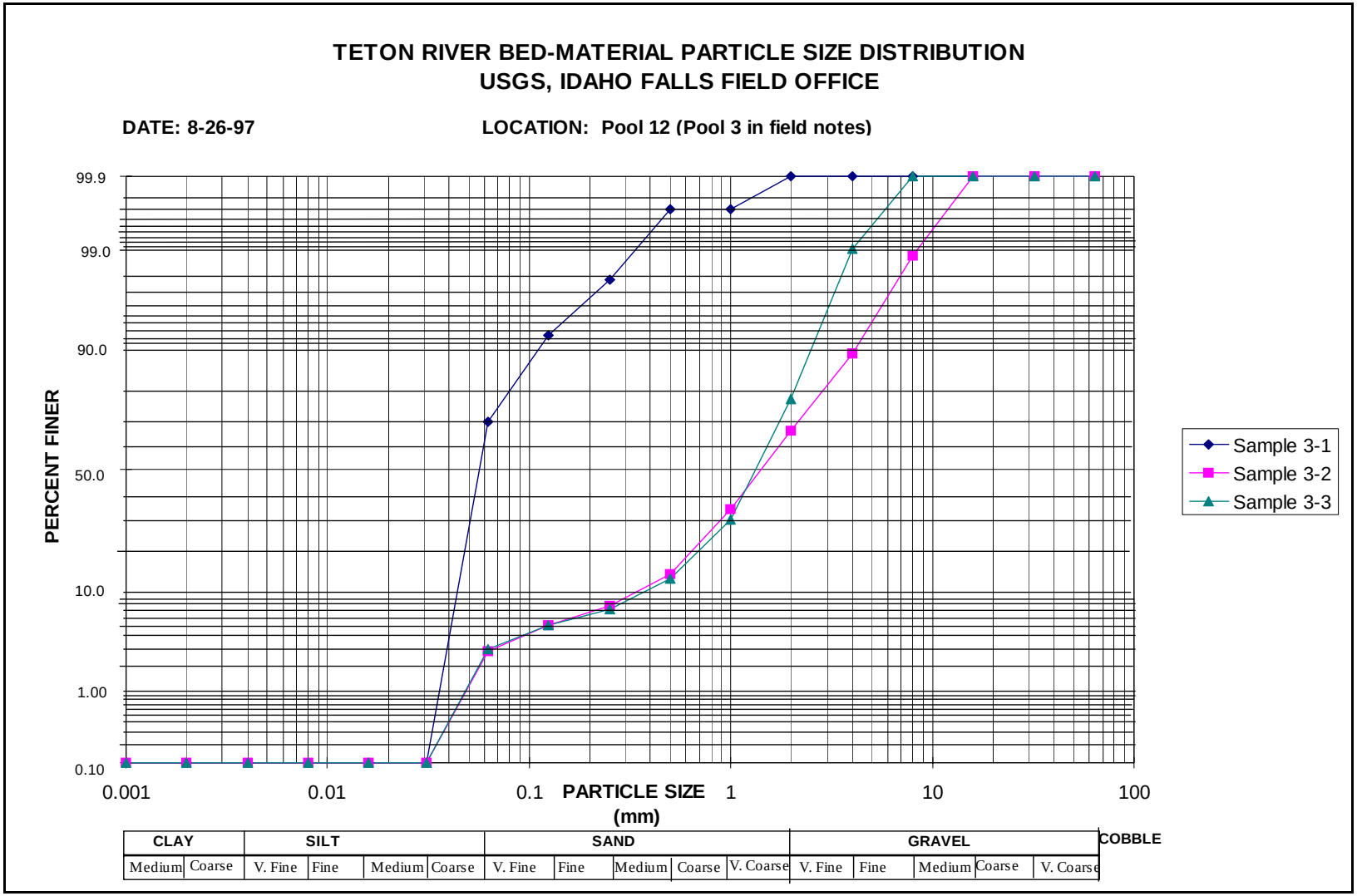


Figure B - 2. - Particle size distribution plot corresponding to bed - material samples in Pool 12.

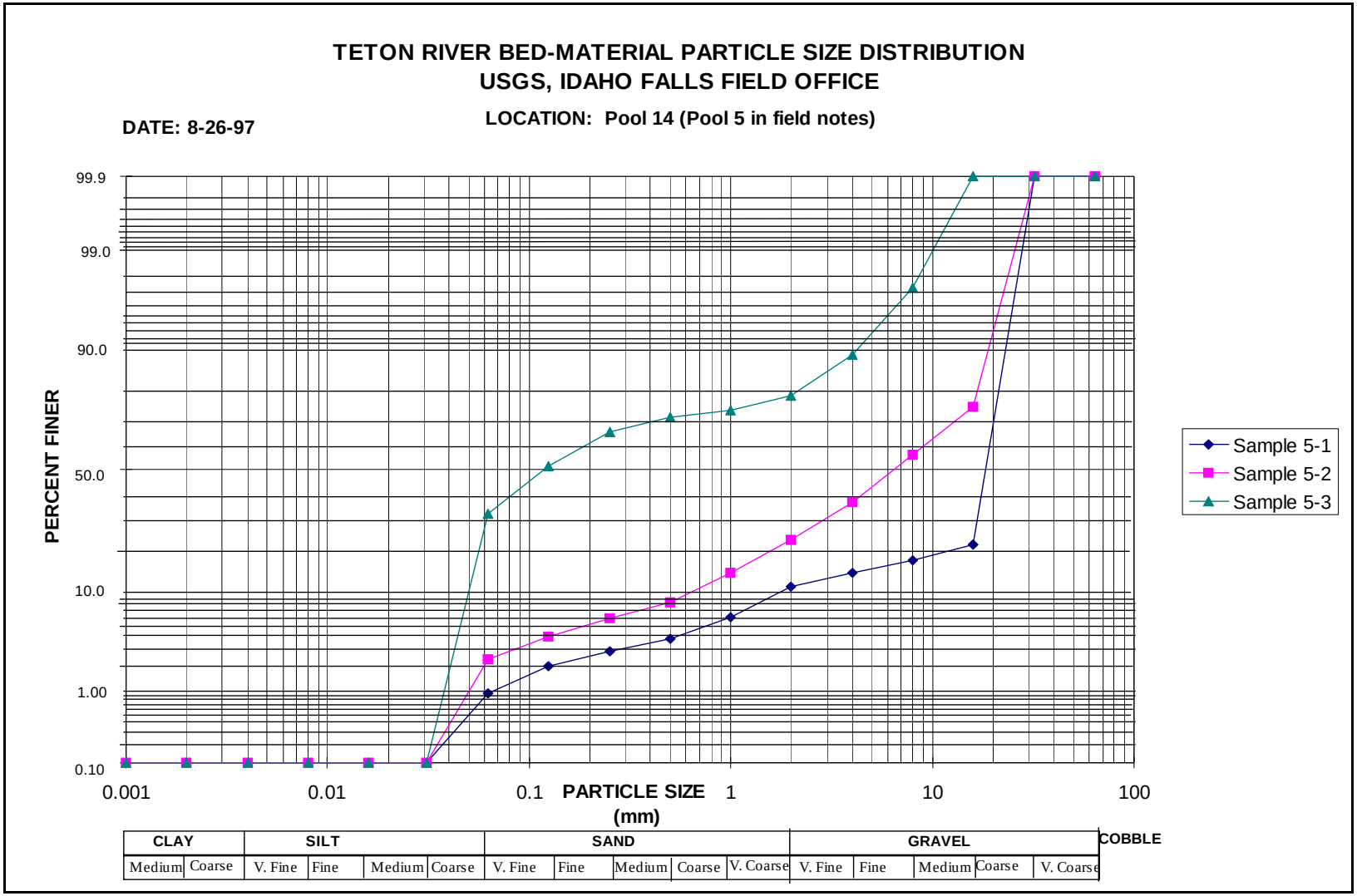


Figure B - 3. - Particle size distribution plot corresponding to bed - material samples in Pool 14.

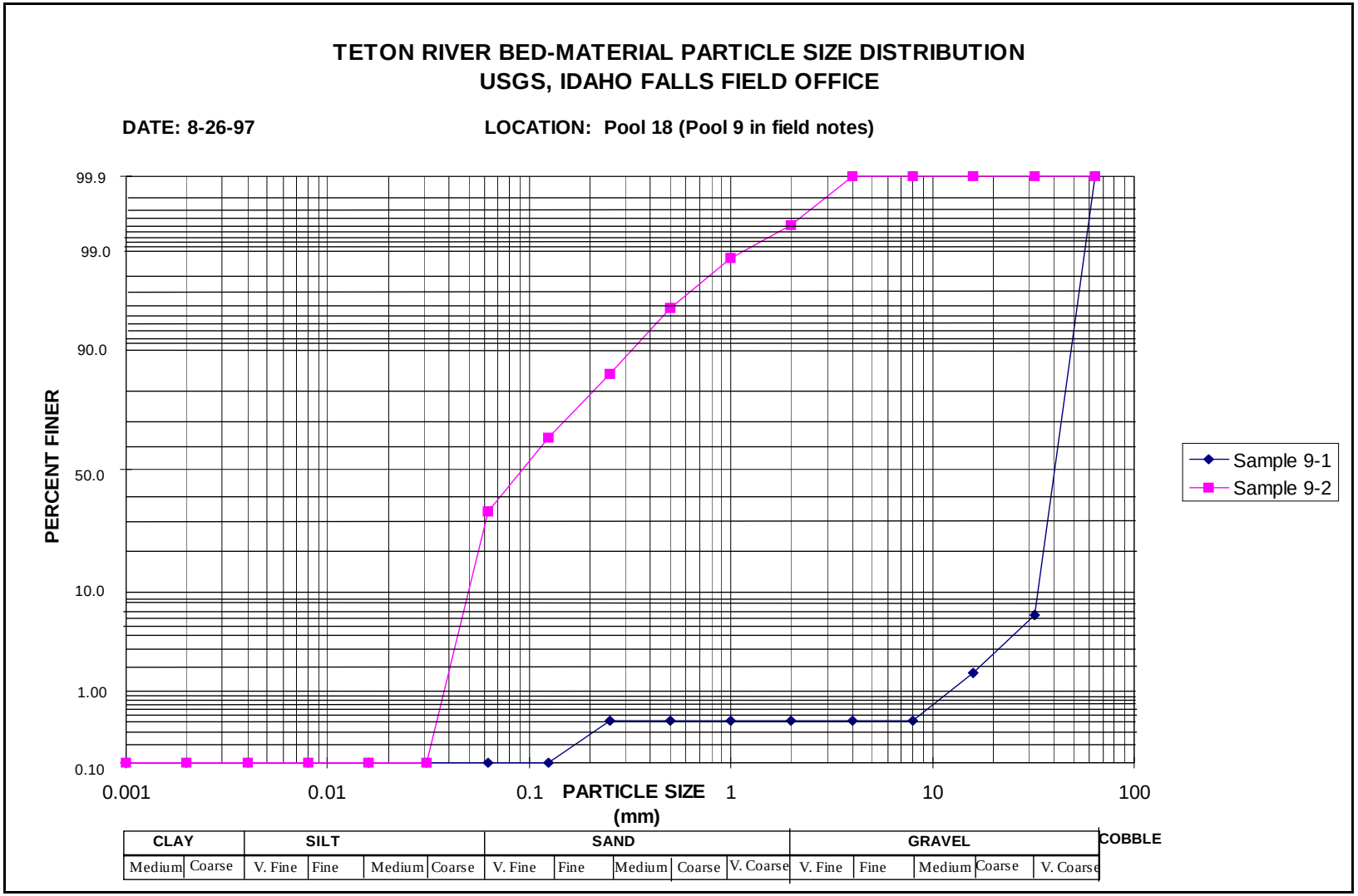


Figure B-4.-Particle size distribution plot corresponding to bed-material samples in Pool 18.

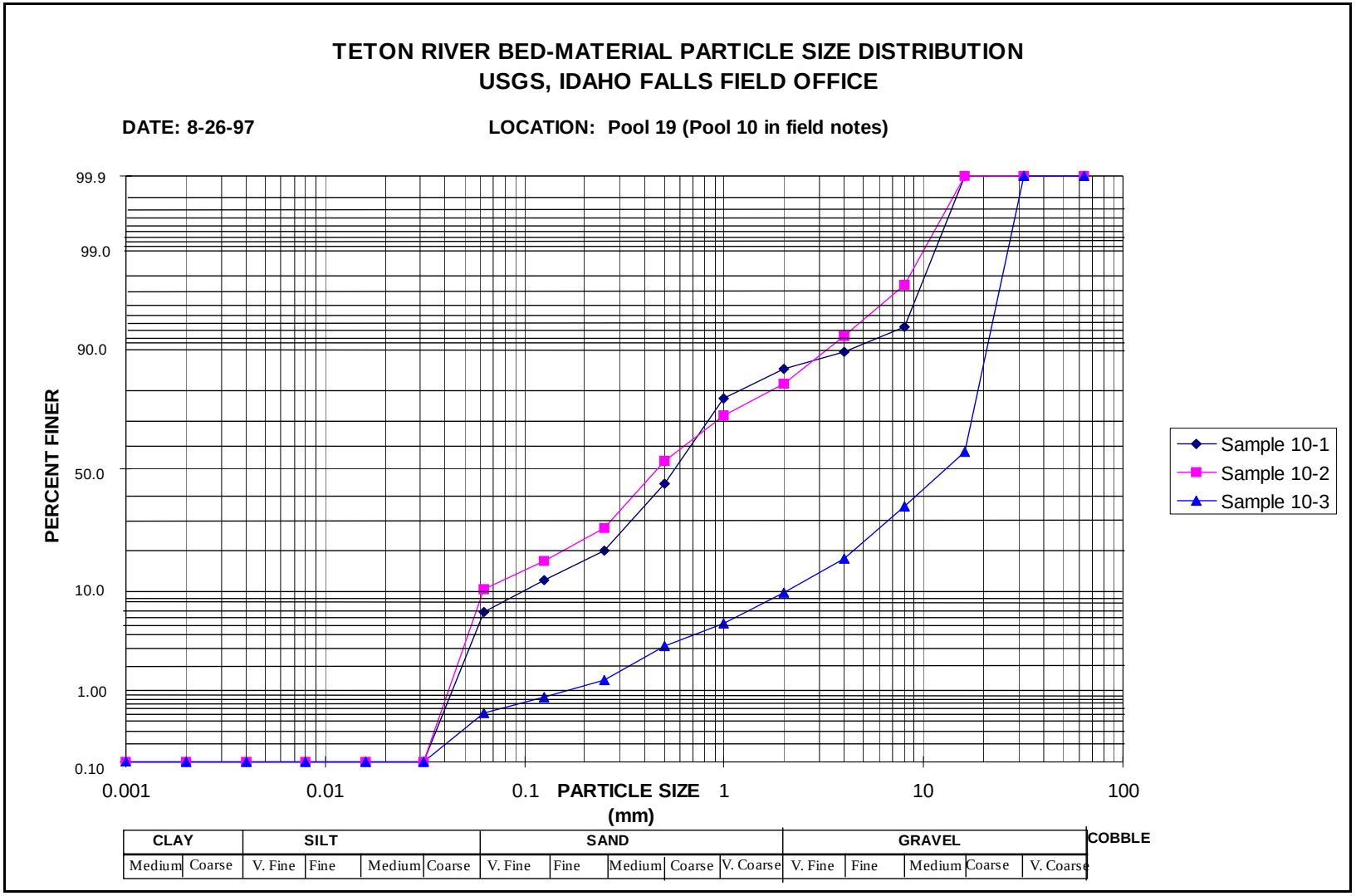


Figure B-5.-Particle size distribution plot corresponding to bed-material samples in Pool 19.

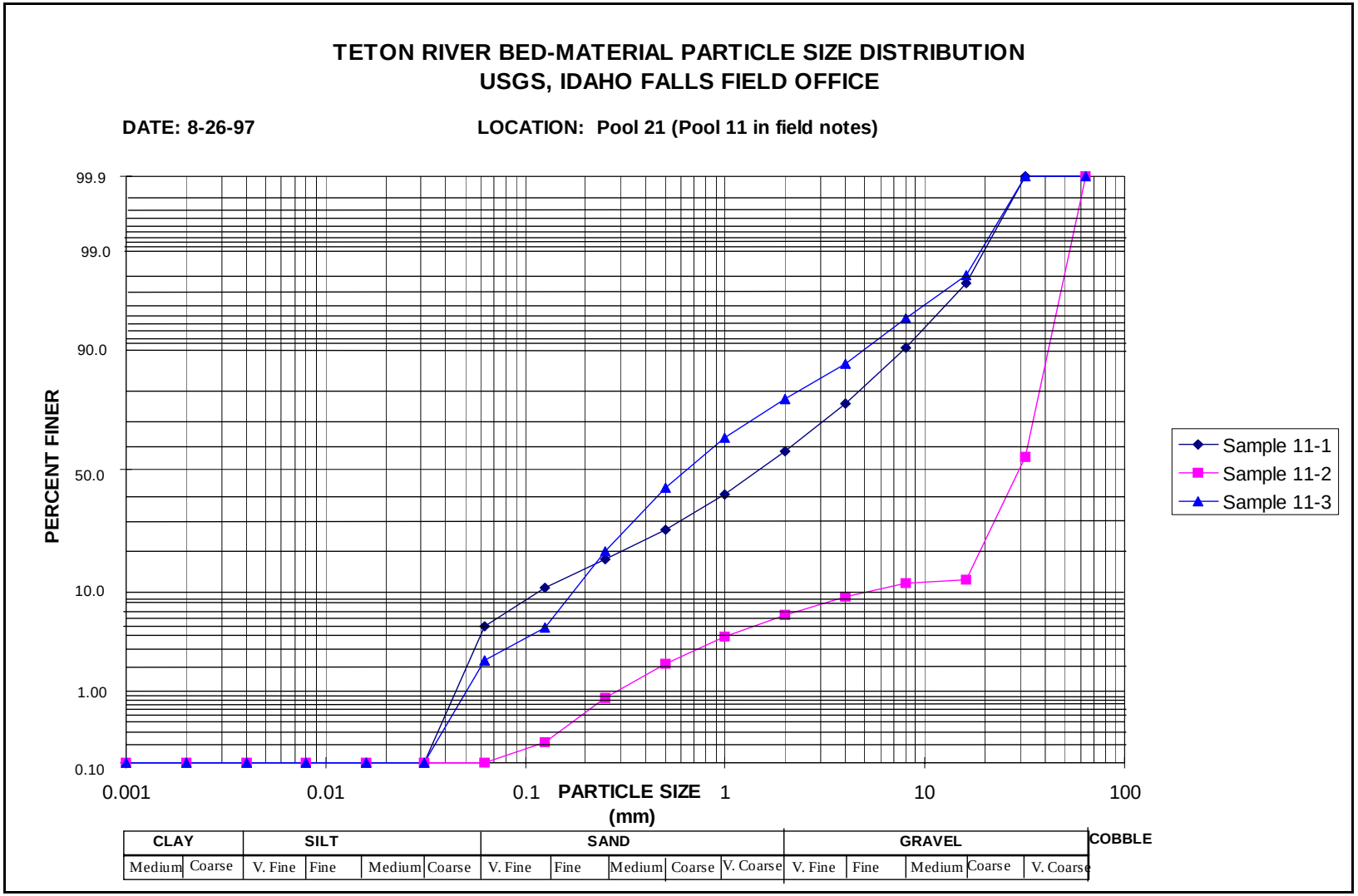


Figure B-6.-Particle size distribution plot corresponding to bed-material samples in Pool 21.

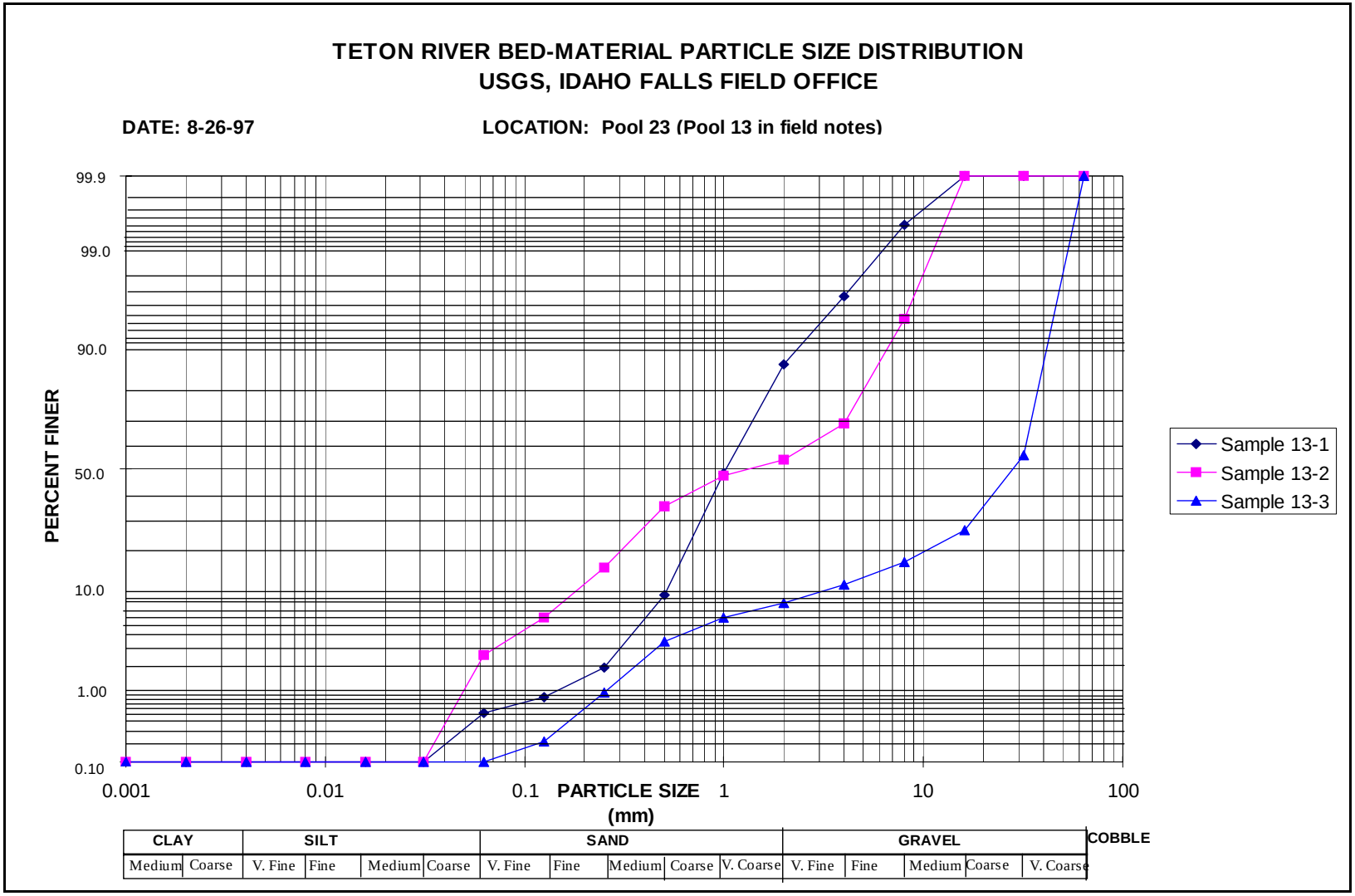


Figure B-7.-Particle size distribution plot corresponding to bed-material samples in Pool 23.

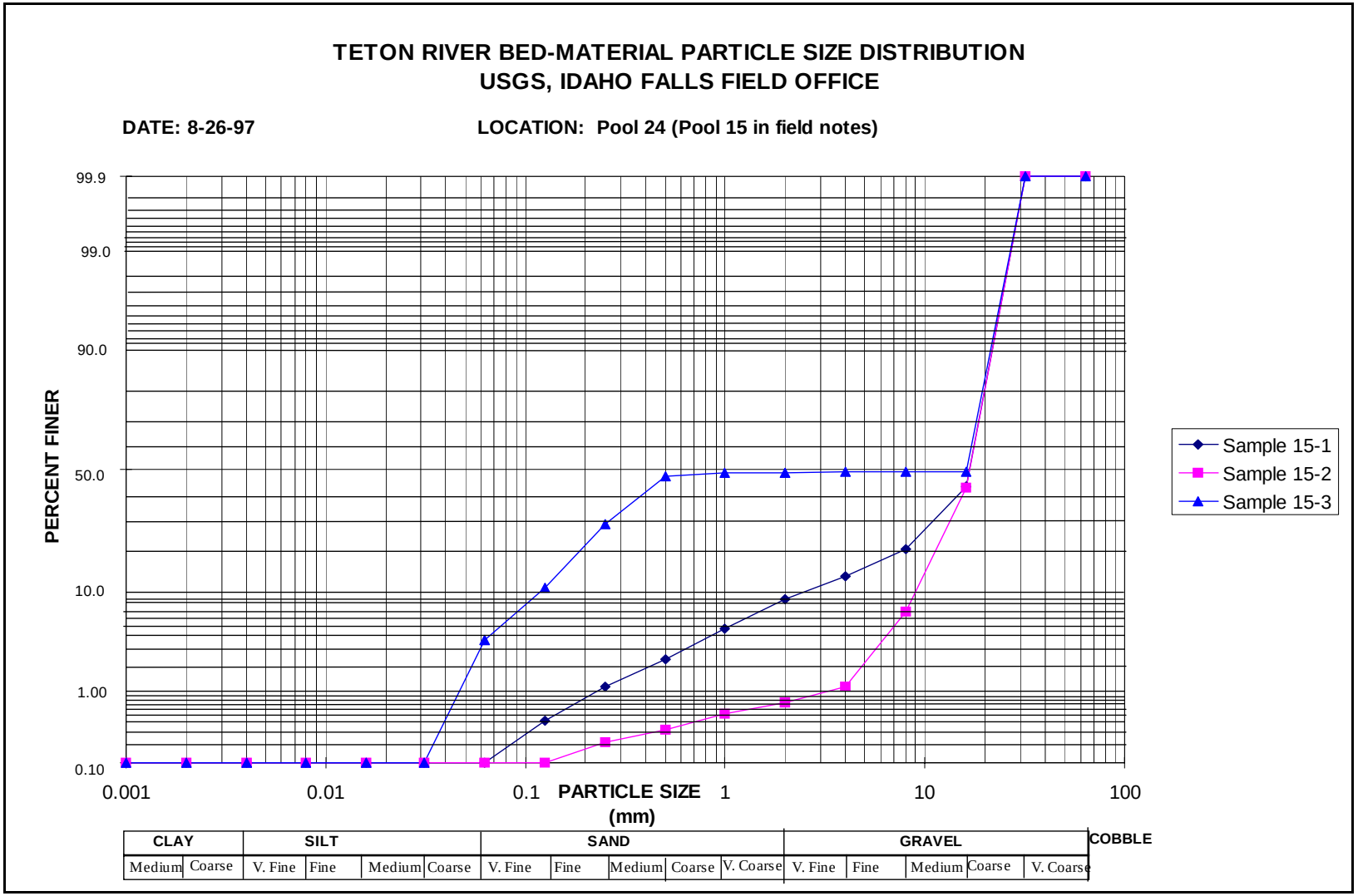


Figure B - 8. - Particle size distribution plot corresponding to bed - material samples in Pool 24.

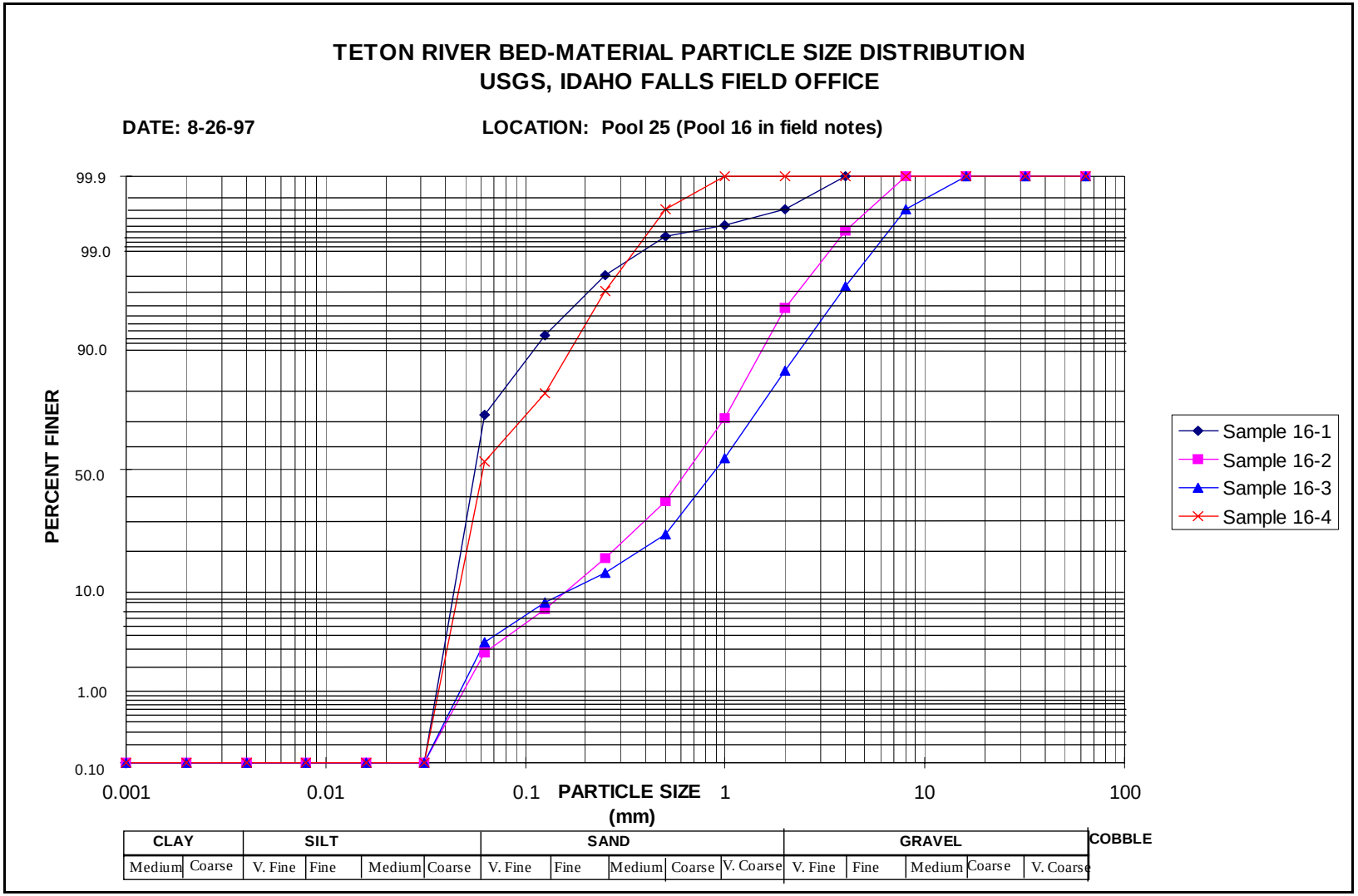


Figure B - 9. - Particle size distribution plot corresponding to bed - material samples in Pool 25.

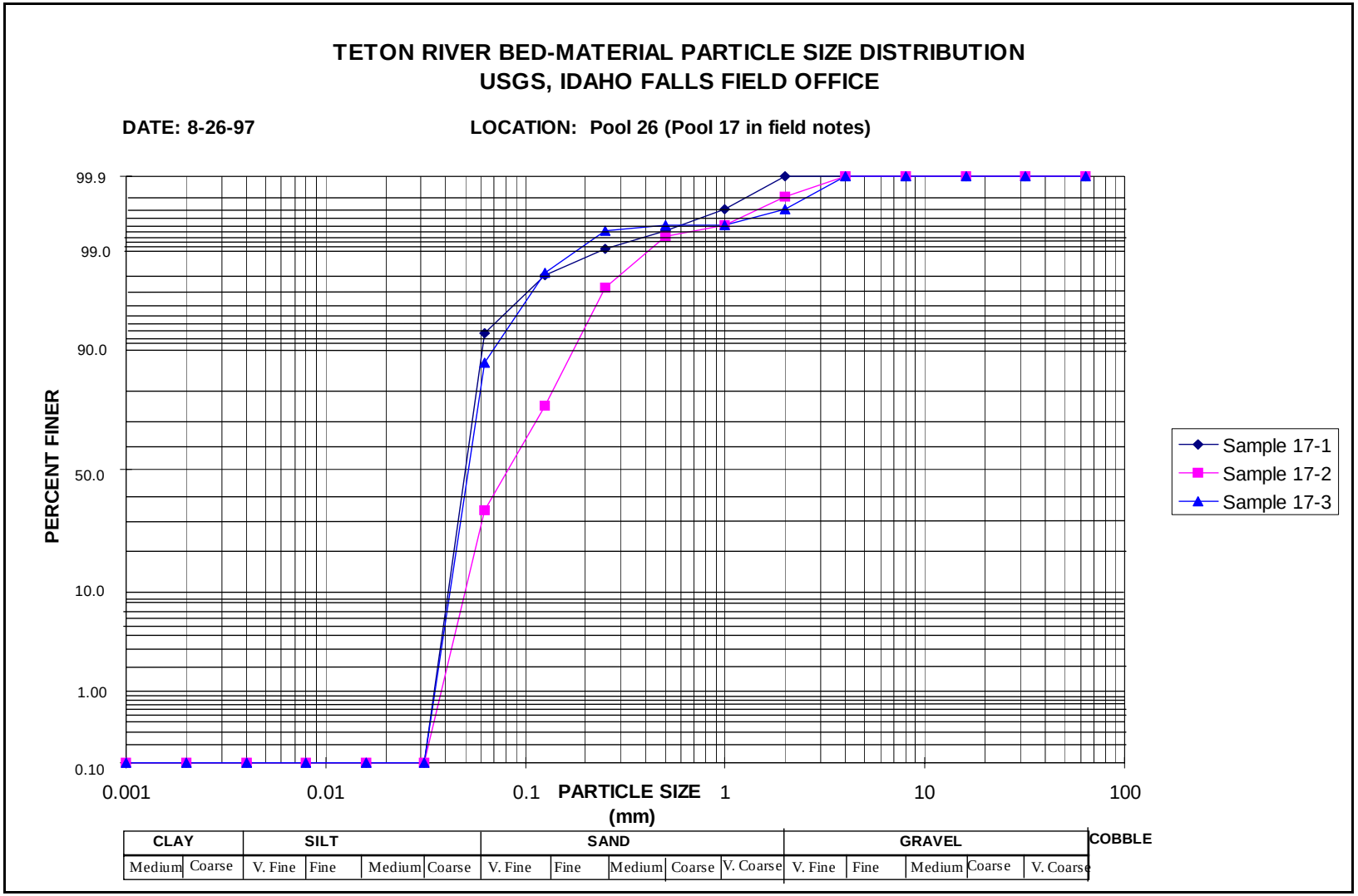


Figure B-10.-Particle size distribution plot corresponding to bed-material samples in Pool 26.

Survey Methodology

Surveys of the Teton River in the former reservoir inundation area were completed in 1997, 1998 and 1999. This section discusses the logistics and methodology used for each of the surveys, and the conversion of the 1997-98 data collected in a local datum (based on 1972 topography maps) to a modern datum (North American Datum (NAD) '83 and North American Vertical Datum (NAVD) '88). Providing all of the data in a modern datum will allow for consistency in any future comparisons of results from this study to additional data collected in the study area. Documentation of the control network has been provided for this purpose (see table C-12).

The first phase of the hydrographic survey included a field reconnaissance in July 1997 to determine the logistical requirements of working in a remote river canyon with limited access (see table C-1). Based on the field reconnaissance trip, it was determined that the hydrographic survey between Spring Hollow and Canyon Creek, and in the borrow ponds would be conducted during a four-day raft trip in August 1997. In July 1998, supplemental data was collected for the Spring Hollow to Canyon Creek reach, and new data collected in a short reach at RM 4 between Canyon Creek and the borrow ponds. The hydrographic survey between Bitch Creek and Spring Hollow was accomplished in July and September of 1999.

Spring Hollow to Teton Dam Site Reach Survey

For the Spring Hollow to Canyon Creek reach, a survey crew would be needed along the canyon rim to provide survey control to the canyon bottom. An additional survey crew would be needed along the river channel to track the position of a survey raft measuring water surface elevations and channel bottom topography. The survey raft would be equipped with a fathometer (depth sounder), reflective prisms, and a hand-held radio (see photo A-13). Additional support rafts were also required to carry people, equipment, and camping supplies. The logistics of the borrow-pond survey were much easier because there was direct road access, a boat ramp, no rapids to navigate, and the survey crew could stay each night in motels.

Because the study would compare existing and predam conditions, it was originally decided to tie the new survey to the local horizontal and vertical datums used to produce a set of predam 1972 topographic maps of the Teton Reservoir area. Prior to surveying the borrow ponds and the Spring Hollow to Canyon Creek reach in August 1997, the existing survey-control network along the top of the canyon was extended to include new control points along the canyon rim (see table C-2). These new control points were established at strategic locations where there was a clear view of the river channel below.

For the river channel survey, a total station survey instrument was set up over the new survey monuments to periodically measure the position of the survey raft (horizontal and vertical coordinates of the water surface) and measure the edge of water through the pools and rapids (see photo A-14). Bathymetric surveys of each pool were conducted by rowing the survey raft across selected survey lines in each pool. Water depths were measured using the fathometer on the raft and the position of the raft was measured by use of the total-station, survey instrument on shore. From the total-station, the horizontal and vertical angles had to be continuously adjusted

to track the position of the moving raft. After each position of the raft was measured, the point-measurement number was relayed by radio to the raft and the position and point number were marked on the depth chart. This procedure provided horizontal and vertical coordinates of the water surface and, by subtracting the water depth, of the channel bottom.

The survey crew first practiced this procedure in the borrow ponds with the use of a motorized, aluminum survey boat (see table C-3). In the borrow ponds, transverse cross-sections were surveyed along with longitudinal profiles and measurements along the edge of the ponds. In addition to surveying the two ponds, data was also collected through the bypass channel that is parallel to the downstream pond. The survey of the borrow ponds was completed in two days, and the same procedure was applied to the Teton River Canyon between Spring Hollow and Canyon Creek.

During the August 1997 Spring Hollow to Canyon Creek raft trip (see table C-4), survey control along the canyon rim was extended to additional points along the canyon bottom. Monuments (steel rebar with aluminum caps) for the control points along the canyon bottom were installed by the survey party rafting through the canyon. Coordinates for these monuments were measured by the survey crew along the canyon rim. Cross sections in eighteen river pools were measured in the reach between Spring Hollow and Canyon Creek. The cross section locations in each river pool were chosen to represent the river pool geometry and were also determined by the ability to maneuver the boat. Additional survey data included longitudinal profiles of the water surface and channel bottom. The high velocity of the riffles and rapids prevented direct measurements of the channel bottom through these sections. Therefore, channel bottom elevations across the riffle or rapid were estimated through hydraulic modeling. Points along the water's edge through the pool and riffle along with canyon topography were taken by reflecting the total station laser off of the bank or ground surface.

Several gaps between Spring Hollow and Canyon Creek were observed in the data set collected in 1997. A supplemental survey trip was scheduled in July 1998 to fill in these gaps and provide additional survey information in the reach between Canyon Creek and the borrow ponds (see tables 7 and 8). Because this was a supplemental survey, a simpler survey procedure was used. The survey raft for the 1998 trip was equipped similarly to the 1997 survey trip, however, an electronic distance meter (EDM) was used to track the survey raft's position from shore. All survey lines during the 1998 survey were run across the channel (perpendicular to flow). The EDM was set up on shore and near the water's edge at one end of the survey line. The horizontal position of the EDM setup was measured using a hand-held GPS Plugger unit. The horizontal coordinates of the temperature and air data loggers placed during this field trip along the river were also measured using the hand-held GPS PLUGGER unit (Bowser, 1999). The EDM was used to continuously measure the horizontal distance along each survey line. Because the EDM was on the survey line and typically near the water surface elevation, only relatively minor adjustments in the horizontal and vertical angles were

necessary to track the position of the survey raft. As the EDM continuously tracked the distance to the survey raft, the distances, at regular distance intervals, were relayed to the survey raft by radio.

The discharge recorded at the USGS St. Anthony gaging station during the July 1998 survey of 1,220 ft^3/s was very similar to the discharge of 1,400 ft^3/s recorded during the August 1997 survey in this reach (USGS gaging station 13055000). Because the water surface across each pool was assumed to be level and the discharges for both surveys were similar, the water surface elevations for the 1998 cross section lines were estimated from the average pool water surfaces measured in August 1997. The measured water depths and distance between measurements could then be subtracted from the estimated pool elevation to develop a channel bottom profile for each cross section.

An additional reach of the Teton River was also surveyed at RM 4 in 1998 to document the characteristics of the Teton River from Canyon Creek (RM 5.0) downstream to the borrow ponds (RM 1.5). The surveyed river reach is short (800 ft), and consists of shallow pools and riffles with floodplains on the south side of the canyon. The same methodology as used to supplement the 1997 data upstream of Canyon Creek was used to survey the channel bottom at six cross sections in this reach. Two of the cross sections were located upstream of a riffle, the next two cross sections were located in the riffle, and the last two cross sections were located downstream of the riffle. Additional survey data was collected to document the right floodplain topography at each cross section using a total station instrument.

A longitudinal water surface profile was developed from 1997 measured data from Spring Hollow to Canyon Creek. Water surface elevations tended to rise slightly in the downstream direction, and fluctuated up to ± 1 foot across any transverse line in a pool (see figure 3 in report). In contrast to the measured data, field observations noted that each rapid backs up water to create a pool with a relatively flat water surface with a small slope in the downstream direction. It was determined that the 1 foot vertical fluctuation in water surface elevations across any section of river was due to survey limitations and could not be resolved. When the moving target of the survey raft was being tracked with the total-station, survey instrument, the horizontal angles tended to change much faster than the vertical angles which measure the water-surface elevations of the nearly level pools. Consequently, the vertical angles were not adjusted as frequently as the horizontal angles and some error was introduced in the individual measurements of the water-surface elevation. However, the average water surface elevation in each pool was believed to be accurate.

Table C-1.—Initial Field Reconnaissance from Spring Hollow to borrow ponds.

Dates: July 21, 1997
Participants: Dick Bauman (Environmental Specialist, USBR Snake River Area Office East, Jackson, WY) Cory Stolsig (Supervisory Land Surveyor, USBR Ephrata Office, Ephrata, WA) Tim Randle (Hydraulic Engineer, USBR Technical Service Center, Denver, CO) Dean Ostenaa (Geologist, USBR Technical Service Center, Denver, CO) Ralph Klinger (Geologist, USBR Technical Service Center, Denver, CO) Allen Lockhart (Geologist, USBR Pacific Northwest Regional Office, Boise, ID) Bill Schrader (Fishery Biologist, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID) Kim Ragotzkie (Biologist, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID) Steve Lipscomb (Hydrologist, USGS, Boise, ID) Nathan Jacobson (Hydrologist, USGS, Idaho Falls, ID)

Table C-2.—Survey to extend existing control network to the canyon rim.

Dates: August 4-8, 1997
Participants: Cory Stolsig (Supervisory Land Surveyor, USBR Ephrata Office, Ephrata, WA) survey party chief Sam Trachsler (Surveyor, USBR Ephrata Office, Ephrata, WA) survey crew Doug Schmidt (Materials Engineering Technician, USBR Ephrata Office, Ephrata, WA) survey crew Irving Lawyer (Engineering Technician, USBR Pacific Northwest Regional Office, Boise, ID) survey crew
Equipment: Total station survey instruments

Table C-3.—Hydrographic survey of borrow ponds.

Dates: August 9-10, 1997
River flow at USGS gaging station near St. Anthony, Idaho (13055000): 1,200 ft^3/s
Participants: • Cory Stolsig (Supervisory Land Surveyor, USBR Ephrata Office, Ephrata, WA) survey party chief • Doug Schmidt (Materials Engineering Technician, USBR Ephrata Office, Ephrata, WA) survey crew • Tim Randle (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), fathometer operator • Bill Schrader (Fishery Biologist, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID), boat pilot
Equipment: • Aluminum boat (Idaho Department of Fish and Game, Idaho Falls, ID) • Total station survey instrument (USBR Ephrata Office, Ephrata, WA) • Raytheon Fathometer (USBR Technical Service Center, Denver, CO)

Table C-4.—Hydrographic survey of river channel from Spring Hollow to Canyon Creek.

Survey task: Hydrographic survey of river channel from Spring Hollow to Canyon Creek.
Dates: August 11-14, 1997
River flow at USGS gaging station near St. Anthony, Idaho (13055000): 1,400 ft^3/s
Participants: • Dick Bauman (Environmental Specialist, USBR Snake River Area Office East, Jackson, WY) Area Office Study Leader and boat pilot • Cory Stolsig (Supervisory Land Surveyor, USBR Ephrata Office, Ephrata, WA) survey party chief and instrument operator in the canyon • Sam Trachsler (Surveyor, USBR Ephrata Office, Ephrata, WA) survey crew along canyon rim • Irving Lawyer (Surveyor, USBR Pacific Northwest Regional Office, Boise, ID) survey crew along canyon rim • Tim Randle (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), fathometer operator • Bill Schrader (Fishery Biologist, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID), boat pilot • Jason Hammond (Biological Aid, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID), boat pilot
Equipment: • Large inflatable raft (Snake River Area Office East, Jackson, WY) • Small inflatable raft (Idaho Department of Fish and Game, Idaho Falls, ID) • Catoraft (rented in Idaho Falls by Snake River Area Office East, Jackson, WY) • Total station survey instrument (USBR Ephrata Office, Ephrata, WA) • Handheld radios (USBR Ephrata Office, Ephrata, WA) • Raytheon Fathometer (USBR Technical Service Center, Denver, CO) • Portable generator, and other miscellaneous supplies (USBR Technical Service Center, Denver, CO)

Table C-5.—Field Reconnaissance from Felt Dam Powerhouse to Spring Hollow.

Dates: July 20, 1998

River flow at USGS gaging station near St. Anthony, Idaho (13055000): 1,290 ft^3/s

Participants:

- Dick Bauman (Environmental Specialist, USBR Snake River Area Office East, Jackson, WY) Area Office Study Leader and boat pilot
- Tim Randle (Hydraulic Engineer, USBR Technical Service Center, Denver, CO) survey leader and EDM operator)
- Jennifer Bountry (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), fathometer operator
- Ralph Klinger (Geologist, USBR Technical Service Center, Denver, CO), geomorphic mapping
- Allen Lockhart (Geologist, USBR Pacific Northwest Regional Office, Boise, ID), landslide debris fans measurements
- Steven Bowser (Environmental Engineer, USBR Technical Service Center, Denver, CO), installation of temperature (air and water) data loggers
- T. Ed Beddow (Wildlife Biologist, USBR Technical Service Center, Denver, CO), vegetation mapping
- Joe Curry (District Conservation Officer, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID)
- John Hanson (Conservation Officer, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID)
- Mike Jones (Fishery Technician, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID)
- Doug Petersen (Conservation Officer, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID)
- Bill Schrader (Fishery Biologist, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID)
- Brian Spicer (Biological Aid, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID)
- Greg Tourtlotte (Regional Supervisor, Idaho Department of Fish and Game, Panhandle Region, Coeur d' Alene, ID)

Equipment:

- Large inflatable raft (Snake River Area Office East, Jackson, WY)
- Large inflatable raft (USBR Technical Service Center, Denver, CO)
- Large inflatable raft (Idaho Department of Fish and Game, Idaho Falls, ID)
- Small inflatable raft (Idaho Department of Fish and Game, Idaho Falls, ID)

Table C-6.—Supplemental hydrographic survey of river channel from Spring Hollow to Canyon Creek and downstream of Canyon Creek at RM 4.

Dates: July 20-23, 1998

River flow at USGS gaging station near St. Anthony, Idaho (13055000): average of 1,220 ft^3/s

Participants:

- Dick Bauman (Environmental Specialist, USBR Snake River Area Office East, Jackson, WY) Area Office Study Leader and boat pilot
- Tim Randle (Hydraulic Engineer, USBR Technical Service Center, Denver, CO, survey leader and EDM operator)
- Jennifer Bountry (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), fathometer operator
- Ralph Klinger (Geologist, USBR Technical Service Center, Denver, CO), geomorphic mapping
- Allen Lockhart (Geologist, USBR Pacific Northwest Regional Office, Boise, ID), landslide debris fans measurements
- Steven Bowser (Environmental Engineer, USBR Technical Service Center, Denver, CO), installation of temperature (air and water) data loggers
- T. Ed Beddow (Wildlife Biologist, USBR Technical Service Center, Denver, CO), vegetation mapping

Equipment:

- Large inflatable raft (Snake River Area Office East, Jackson, WY)
- Small inflatable raft (Idaho Department of Fish and Game, Idaho Falls, ID)
- Catoraft (rented in Idaho Falls by Snake River Area Office East)
- Total station survey instrument (USBR Ephrata Office, Ephrata, WA)
- Handheld radios (USBR Ephrata Office, Ephrata, WA)
- Raytheon Fathometer (USBR Technical Service Center, Denver, CO)
- Portable generator, and other miscellaneous supplies (USBR Technical Service Center, Denver, CO)

Table C-7.—Field review from Spring Hollow to upstream end of borrow ponds.

Dates: July 24, 1998

River flow at USGS gaging station near St. Anthony, Idaho (13055000): 1,140 ft^3/s

Participants:

- Dick Bauman (Environmental Specialist, USBR Snake River Area Office East, Jackson, WY)
- Tim Randle (Hydraulic Engineer, USBR Technical Service Center , Denver, CO)
- Dean Ostenaa (Geologist, USBR Technical Service Center, Denver, CO)
- Ralph Klinger (Geologist, USBR Technical Service Center, Denver, CO,)
- Brent Carter (Supervisory Geologist, USBR Pacific Northwest Regional Office, Boise, ID)
- Allen Lockhart (Geologist, USBR Pacific Northwest Regional Office, Boise, ID)
- Bill Schrader (Fishery Biologist, Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID)

Horizontal Datum Conversion

In a previous study, a set of 1972 contour maps (based on 1972 aerial photographs) were used to display interpretations of landslides that occurred prior to the failure of Teton Dam (predam), during the reservoir filling, and after the failure of the dam (Magleby, 1981). These maps provided the original control network used to survey the existing conditions data between Spring Hollow and Teton Dam. While these maps worked well for displaying predam landslide interpretations, they did not work well for displaying post-failure interpretations or any of the new existing conditions survey data collected because after the dam failure the topography in the canyon was altered significantly. To provide a new base map that represents existing topography in the canyon rather than predam topography, a set of contour maps based on 2000 aerial photography are anticipated to be developed.

In order to develop the new existing conditions contour maps and present all of the project data in a consistent modern datum, the control network along the canyon rim was resurveyed using survey-grade Global Positioning System (GPS) units in June 1999 (table C-9). Based on this new survey, it was determined that the 1972 predam contour maps were in a local horizontal and vertical datum. The GPS survey of the rim provided data which was used to develop horizontal conversions from the local datum to NAD ‘83 (table C-8).

Table C-8.—Datum conversions from the predam 1972 topographic map to NAD ‘83.

Original 1972 control network to Idaho East NAD ‘27 and NAVD ‘29 datum			Idaho East NAD ‘27 and NAVD ‘29 to Idaho East NAD ‘83 and NAVD ‘88		
Northing (feet)	Easting (feet)	Elevation (feet)	Northing (feet)	Easting (feet)	Elevation (feet)
-200.5	-163.8	see figures C-1 and C-2	-22.9	+155952.5	see figures C-1 and C-2

Table C-9.—Control point survey for 1997 aerial photograph rectification and resurvey of control network in modern datum.

Survey task: Control point survey for 1997 aerial photograph rectification process used to develop the new existing conditions contour map and resurvey of existing control network along the canyon rim to provide datum conversions from the 1972 contour map data to the modern datum.
Dates: June 1999
Participants: • Cory Stolsig (Supervisory Land Surveyor, USBR Ephrata Office, Ephrata, WA) GPS survey • Sam Trachsler (Surveyor, USBR Ephrata Office, Ephrata, WA) GPS survey crew • Irving Lawyer (Surveyor, USBR Pacific Northwest Regional Office, Boise, ID) GPS survey crew • Tim Randle (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), GPS survey crew
Equipment: • Survey grade Global positioning system (GPS) survey instrument (USBR TSC, Denver, CO and Ephrata Office, Ephrata, WA) • Handheld radios (USBR Ephrata Office, Ephrata, WA)

Vertical Datum Conversion

Across the river channel (water surface elevations), 5-foot contour lines were pulled off the 1972 maps and assumed to be in a NAVD ‘29 datum. These vertical water surface elevations were converted to a NAVD ‘88 datum and plotted by river miles from Teton Dam with measured existing conditions water surface elevations from Spring Hollow to Canyon Creek. Because the river discharge of 1,400 ft^3/s recorded during the 1997 survey is approximately twice the discharge that the 1972 topographic maps were based on, the hydraulic model was used to adjust the 1997 water surface elevations down to the lower discharge of 739 ft^3/s for comparison.

Figure C-1 shows the water surface profiles generated by HEC-RAS for the existing conditions at 739 ft^3/s and the original water surface profiles pulled from the 1972 contour maps (5-foot contours assumed to be NAVD ‘29 and converted to NAVD ‘88 datum). Note that the 1972 contours are only measured at 5-foot changes in elevation. Therefore, the water surface profile between any two contours may not be a straight line as shown, but more of a pool, riffle scenario.

Because of the higher discharge and the landslide constrictions, the water surface elevations measured in 1997 should be equal to or higher than the water surface elevations on the 1972 topographic maps, even in reaches unaffected by landslides. The only exception is the river channel upstream of Linderman Dam. In 1972, this dam was in operation and created a pool that backed up water to the upstream end of pool 15, and a 10-foot drop in water surface elevations across the dam. Today, the drop in water surface elevation across the remaining portion of the dam is only 2 feet.

The comparison showed that the relative 5-foot elevation difference between the 1972 contours appeared to be correct, but the water surface elevations did not match up with the measured water surface elevations as expected. There were 3 specific places where the river channel and water surface elevation is estimated to not have changed . These areas include downstream of the last rapid formed from a 1976 landslide near the confluence with Canyon Creek, in a chute of riffles upstream of pool 24 that did not have any 1976 landslide activity, and near the location of Spring Hollow where a drop in water surface had existed prior to the dam failure due to an island formation. In addition, the water surface could be estimated at the top of pool 15 to match existing conditions because of observations about Linderman Dam operations in 1972.

In these four areas, the 1972 contours were shifted to match the existing water surface elevations. In between these four areas, a weighted shift was applied to maintain the relative 5-foot elevation difference between contour lines while shifting the contours to match the NAVD ‘88 datum. A hydraulic model was developed to estimate the predam water surface. The existing channel geometry was adjusted based on field observations and aerial photograph comparisons of predam versus post-failure conditions. The computed predam water surface was also plotted in figure C-1 with the measured water surface elevations and shifted 1972 contours. The 1972 contours were used to calibrate the predam hydraulic model to match water surface elevations.

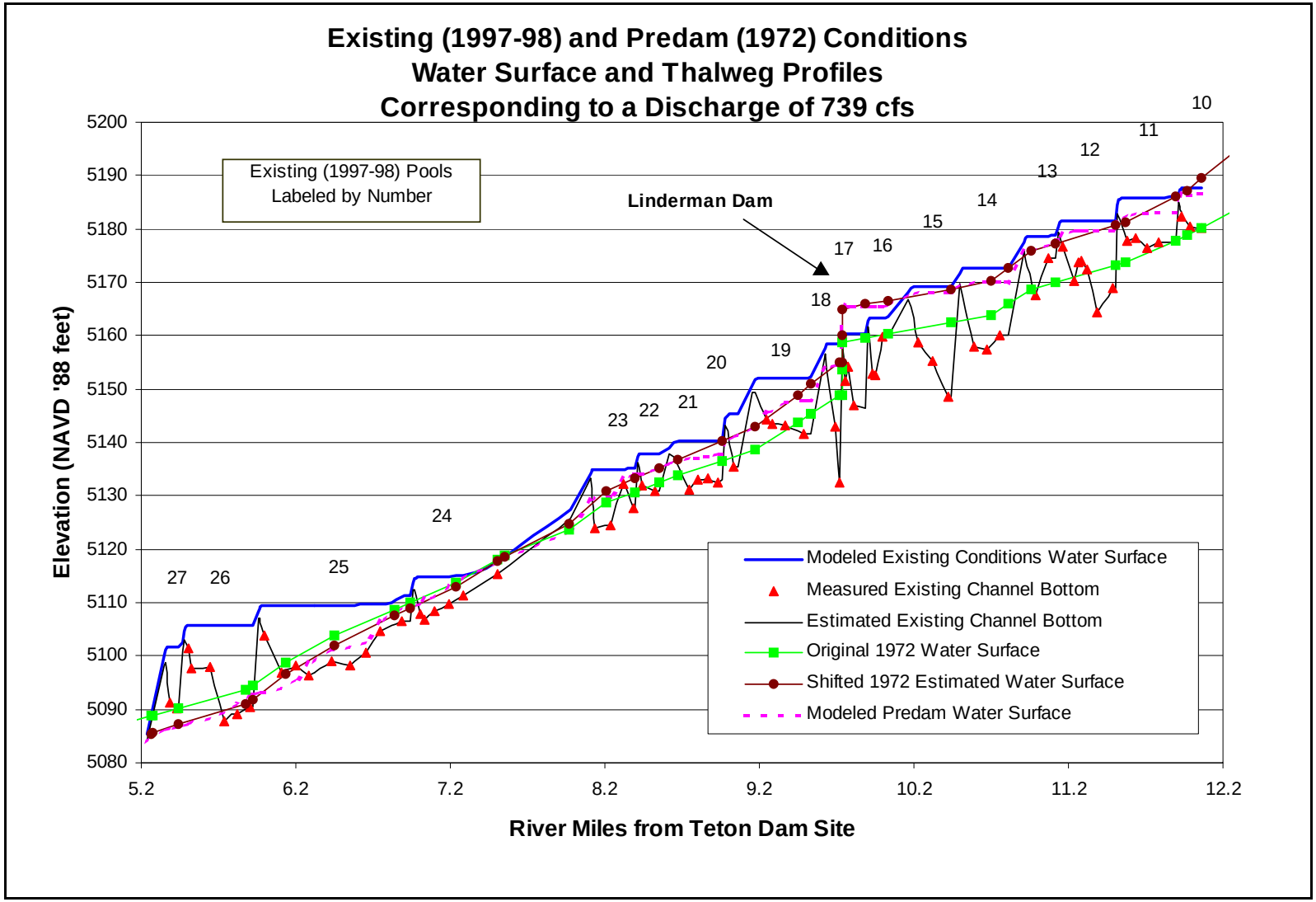


Figure C-1.— Conversion of 1972 5-foot contours to NAVD '88 datum in the Spring Hollow to Canyon Creek reach of the Teton River.

This same approach of shifting the 1972 water surface elevations was used in the Bitch Creek to Spring Hollow reach to convert the local vertical datum to NAVD ‘88. In this reach, the upstream end of the first pool backed up by a 1976 landslide formed rapid and at Spring Hollow the water surface elevations are estimated to not have changed since the dam failure. The shifted 1972 water surface contours were also plotted with measured water surface elevations and used to calibrate the predam hydraulic model (figure C-2).

Bitch Creek to Spring Hollow Reach Survey

In July 1999, an additional survey was started in the Bitch Creek to Spring Hollow reach to complete the hydrographic coverage of the Teton River canyon in the reservoir inundation area (table C-10). The datum used for this survey was the updated control network in NAD ‘83 and NAVD ‘88 developed with GPS during June 1999. Along the rim, GPS units were used during this survey to shoot down positions to each setup in the river canyon rather than a total station as in prior surveys.

For the river channel survey, a similar methodology was used as in the 1997 survey between Spring Hollow and Canyon Creek. However, a different type of total station was used that automatically tracks the horizontal position of the survey raft rather than having to hand adjust the total station for every shot. This method provided more accurate water surface elevations within each pool than the previous method which caused +/- 1 foot fluctuations (see figure 4 in report). The only limitation to this instrument was edge of water shots, previously measured by reflecting a signal off rocks along the edge of the channel, could not be done. For development of cross section lines, it was estimated that the last point in each survey line was approximately 15 feet from the edge of water during the survey.

The logistics of accessing and navigating this reach of river are difficult and caused delays during the July 1999 survey resulting in only a portion of the survey being completed. Therefore, in September 1999 a supplemental survey using the same methodology as in July 1999 was completed to finish the hydrographic survey in this reach (table C-11).

Because the majority of data was collected in September and the river flows were higher in July than September, the average water surface elevations in each pool for the July data was lowered to the average water surface elevation in the corresponding pool for September to provide a consistent data set correlated to a single river flow.

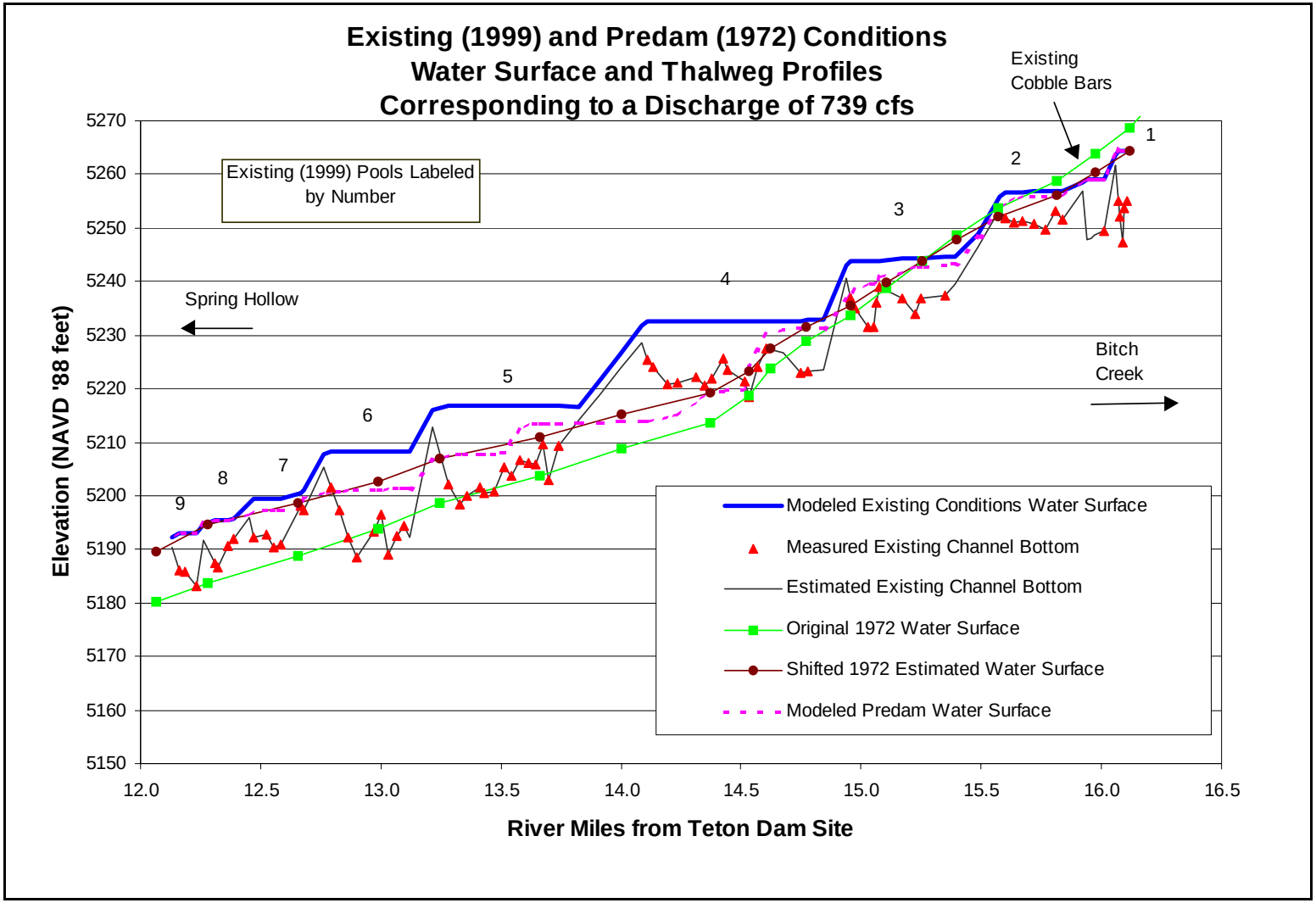


Figure C-2.—Conversion of 1972 5-foot contours to NAVD '88 datum in the Bitch Creek to Spring Hollow reach of the Teton River.

Table C-10.—Hydrographic survey of river channel from Bitch Creek to Spring Hollow.

Survey task: Hydrographic survey of river channel from Bitch Creek to Spring Hollow.
Dates: July 13-15, 1999
River flow at USGS gaging station near St. Anthony, Idaho (13055000): 1,660 ft^3/s
Participants: • Cory Stolsig (Supervisory Land Surveyor, USBR Ephrata Office, Ephrata, WA) survey party chief and instrument operator in the canyon • Sam Trachsler (Surveyor, USBR Ephrata Office, Ephrata, WA) survey crew along canyon rim • Tim Randle (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), boat and fathometer operator • Jennifer Bountry (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), boat and fathometer operator • Marijo Camrud (Hydrologist, USBR Technical Service Center, Denver, CO), data collection aid • Jena Hickey (Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID), data collection aid • Gary Kraus (Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID), survey crew aid • Volunteers (Idaho Department of Fish and Game, Upper Snake Region, Idaho Falls, ID), boat pilots
Equipment: • Large inflatable raft (Snake River Area Office East, Jackson, WY) • Cataraft (USBR Technical Service Center, Denver, CO) • Total station survey instrument (USBR Ephrata Office, Ephrata, WA) • Handheld radios (USBR Ephrata Office, Ephrata, WA) • Raytheon Fathometer (USBR Technical Service Center, Denver, CO)

Table C-11.—Hydrographic survey of river channel from Bitch Creek to Spring Hollow.

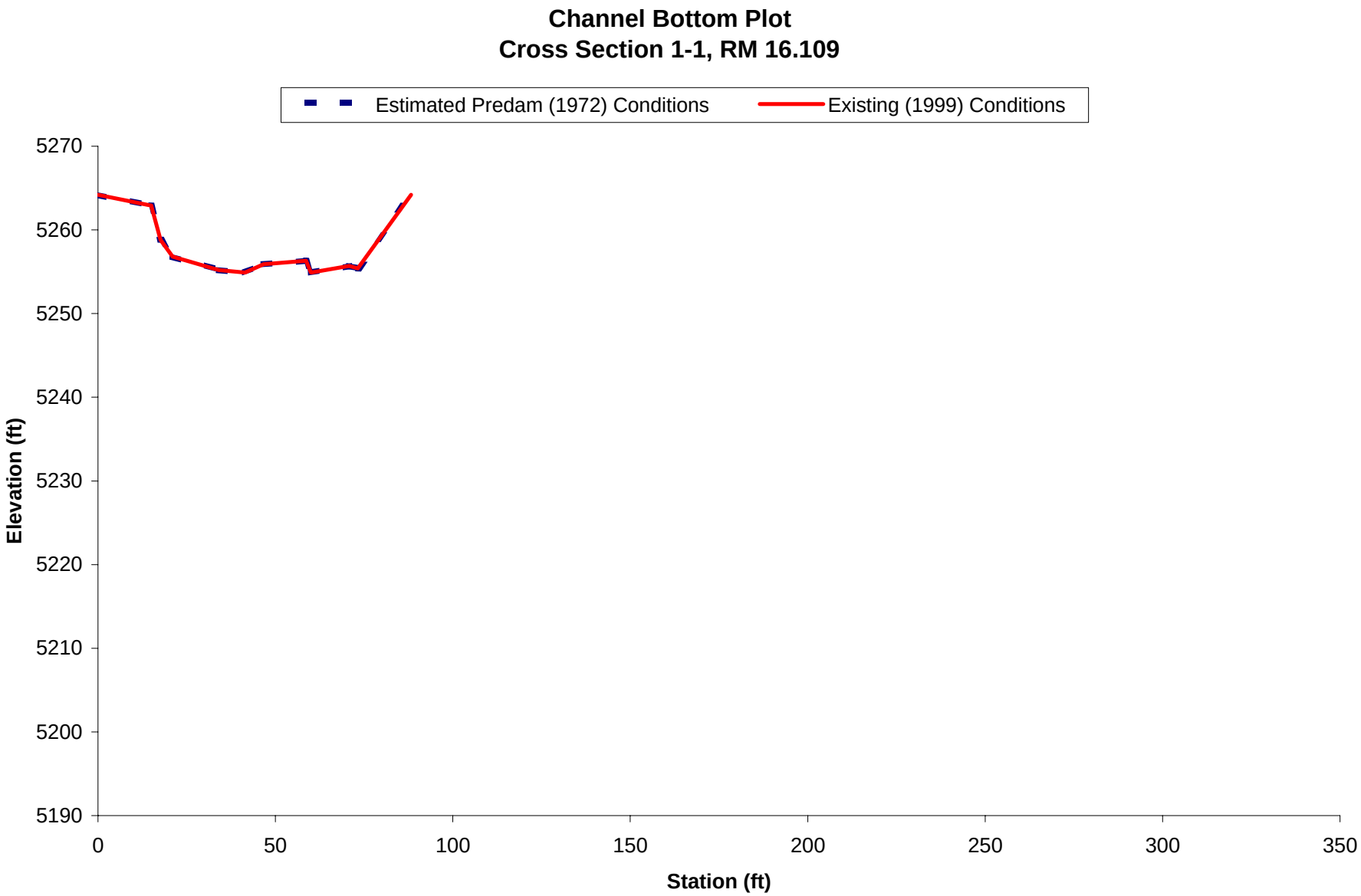
Survey task: Supplemental hydrographic survey of river channel from Bitch Creek to Spring Hollow.
Dates: September 21-23, 1999
River flow at USGS gaging station near St. Anthony, Idaho (13055000): 670 ft^3/s
Participants: • Cory Stolsig (Supervisory Land Surveyor, USBR Ephrata Office, Ephrata, WA) survey party chief and instrument operator in the canyon • Sam Trachsler (Surveyor, USBR Ephrata Office, Ephrata, WA) survey crew along canyon rim • Clint Anderson (Surveyor, USBR Ephrata Office, Ephrata, WA) survey crew along canyon rim • Tim Randle (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), boat and fathometer operator • Jennifer Bountry (Hydraulic Engineer, USBR Technical Service Center, Denver, CO), fathometer operator • Teton River Guides (Hyde Outfitter, Jackson, WY), boat operators
Equipment: • Catarafts (Hyde Outfitter, Jackson, WY) • Cataraft (USBR Technical Service Center, Denver, CO) • Total station survey instrument (USBR Ephrata Office, Ephrata, WA) • Handheld radios (USBR Ephrata Office, Ephrata, WA) • Raytheon Fathometer (USBR Technical Service Center, Denver, CO)

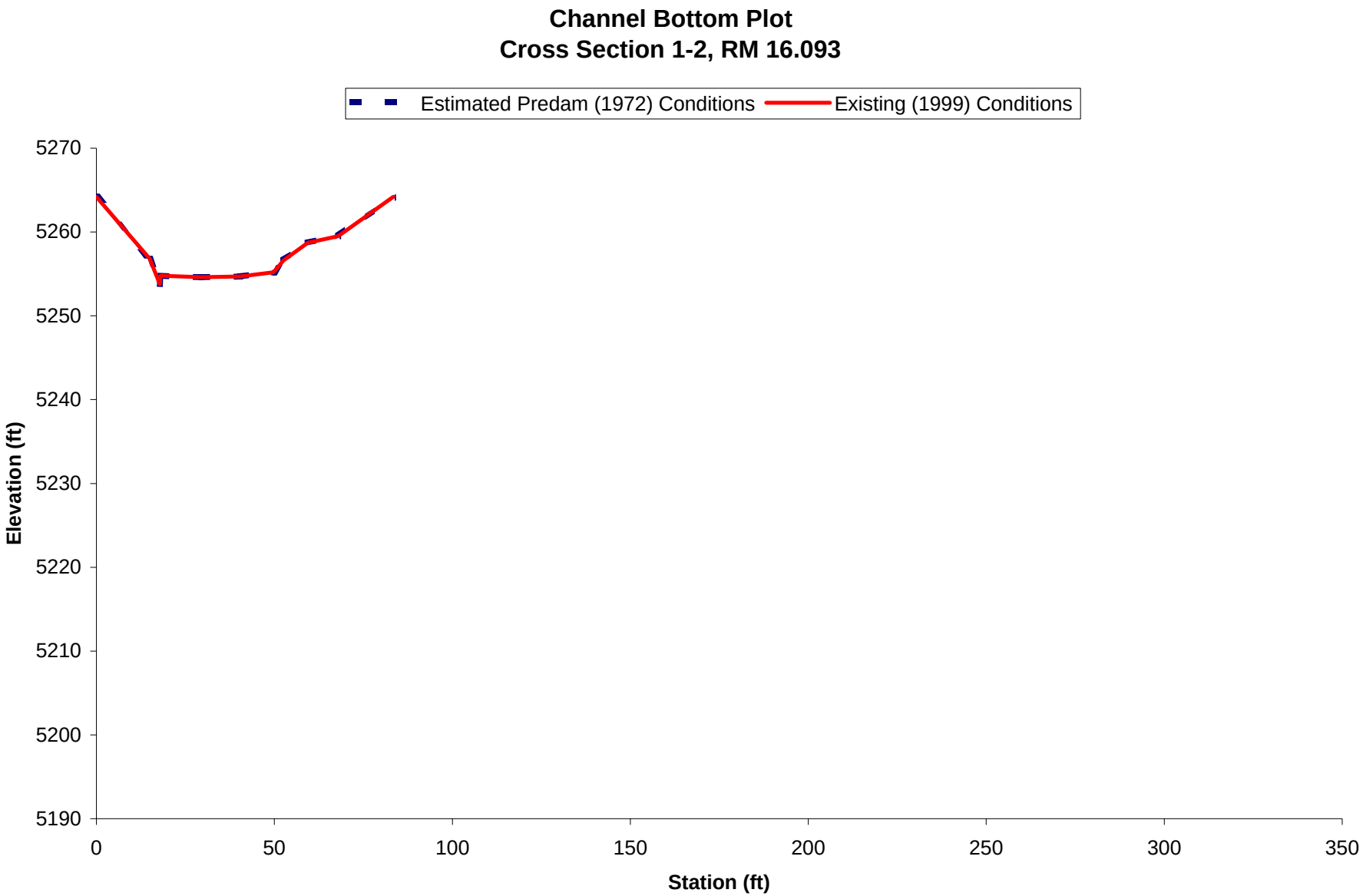
Table C-12.—Control network for Teton River surveys.

Control Point Number	Easting NAD ‘83 (feet)	Northing NAD ‘83 (feet)	Elevation NAVD ‘88 (feet)	Description
Bitch Creek to Spring Hollow Reach Along Canyon Rim (RM 17 to 12)				
30	881792.60	823785.70	5872.08	5/8" Rebar
31	881577.70	824093.80	5956.57	5/8" Rebar
32	878906.00	825001.60	5795.46	5/8" Rebar
33	878501.00	825224.80	5791.26	5/8" Rebar
34	878052.40	825956.10	5792.83	5/8" Rebar
35	877604.20	827533.20	5800.62	5/8" Rebar
36	876083.20	829984.90	5717.70	5/8" Rebar
37	871701.40	831954.70	5607.14	5/8" Rebar
38	872657.00	831034.30	5683.40	5/8" Rebar
Bitch Creek to Spring Hollow Reach Along River Channel (RM 17 to 12)				
50	881858.50	822290.10	5275.05	Mag Nail in Rock
51	882031.70	822911.80	5257.96	Large Nail
52	881276.50	822836.60	5261.11	Mag Nail in Rock
53	879776.90	824086.00	5251.23	Large Spike
54	877933.40	823554.20	5258.54	Large Spike
55	877052.90	825198.90	5266.55	Large Spike
56	876905.00	826732.20	5240.15	Large Spike
57	876282.40	827949.10	5231.63	Large Spike
58	873737.20	829241.30	5227.17	Large Spike
59	878547.60	824201.50	5243.84	Large Nail
60	871772.30	828773.40	5237.84	Large Nail
61	875590.60	829606.40	5221.52	Large Nail
62	871728.40	830542.00	5204.92	Large Nail
63	870923.40	832004.40	5193.73	Large Nail
Spring Hollow to Canyon Creek Reach Along Canyon Rim (RM 12 to 5)				
5005	870862.30	833041.60	5602.93	Large Spike

Control Point Number	Easting NAD '83 (feet)	Northing NAD '83 (feet)	Elevation NAVD '88 (feet)	Description
5006	865610.30	830098.40	5715.82	Large Spike
5012	858939.50	824873.50	5628.45	Set Rebar
5014	856819.60	822104.20	5615.10	Set Rebar
5016	848959.50	821145.20	5581.20	Set Rebar
5017	847284.30	820490.80	5586.58	Set Rebar
5018	845833.80	821103.10	5582.91	Set Rebar
Spring Hollow to Canyon Creek Reach Along River Channel (RM 12 to 5)				
6001	870847.50	832258.10	5199.30	Alum Cap on Rebar
6002	869864.90	832419.30	5196.90	Alum Cap on Rebar
6003	868299.30	831340.80	5196.90	Alum Cap on Rebar
6004	866851.30	830240.80	5190.30	Alum Cap on Rebar
6005	865890.10	829419.50	5187.50	Alum Cap on Rebar
6006	864784.90	828000.30	5192.50	Alum Cap on Rebar
6007	864648.90	826919.40	5186.80	Alum Cap on Rebar
6008	862008.40	824960.30	5168.90	Alum Cap on Rebar
6009	860030.50	825296.80	5161.90	Alum Cap on Rebar
6010	858742.50	823736.00	5158.80	Alum Cap on Rebar
6011	857312.80	821659.50	5144.70	Alum Cap on Rebar
6012	855161.70	821034.00	5143.00	Alum Cap on Rebar
6013	852617.40	820010.70	5126.90	Alum Cap on Rebar
6014	850854.60	819254.90	5122.00	Alum Cap on Rebar
6015	846531.40	819309.30	5116.30	Alum Cap on Rebar
6016	844766.40	820725.80	5118.40	X on Rock
6017	844104.90	820476.90	5120.20	Alum Cap on Rebar
Borrow Ponds Area (Just upstream of Teton Dam at RM 1.5 to .4)				
4999	821742.60	819222.50	5055.70	Large Nail
5001	822110.10	819334.80	5059.10	Large Nail
5002	822668.00	819660.20	5054.00	Alum Cap on Rebar

Control Point Number	Easting NAD ‘83 (feet)	Northing NAD ‘83 (feet)	Elevation NAVD ‘88 (feet)	Description
5003	823696.40	821250.90	5058.90	Alum Cap on Rebar
5004	825648.10	821942.30	5065.80	Rebar


Channel Bottom Plot
Cross Section 1-1, RM 16.109
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
5250
5240
5230
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 1-2, RM 16.093
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5220
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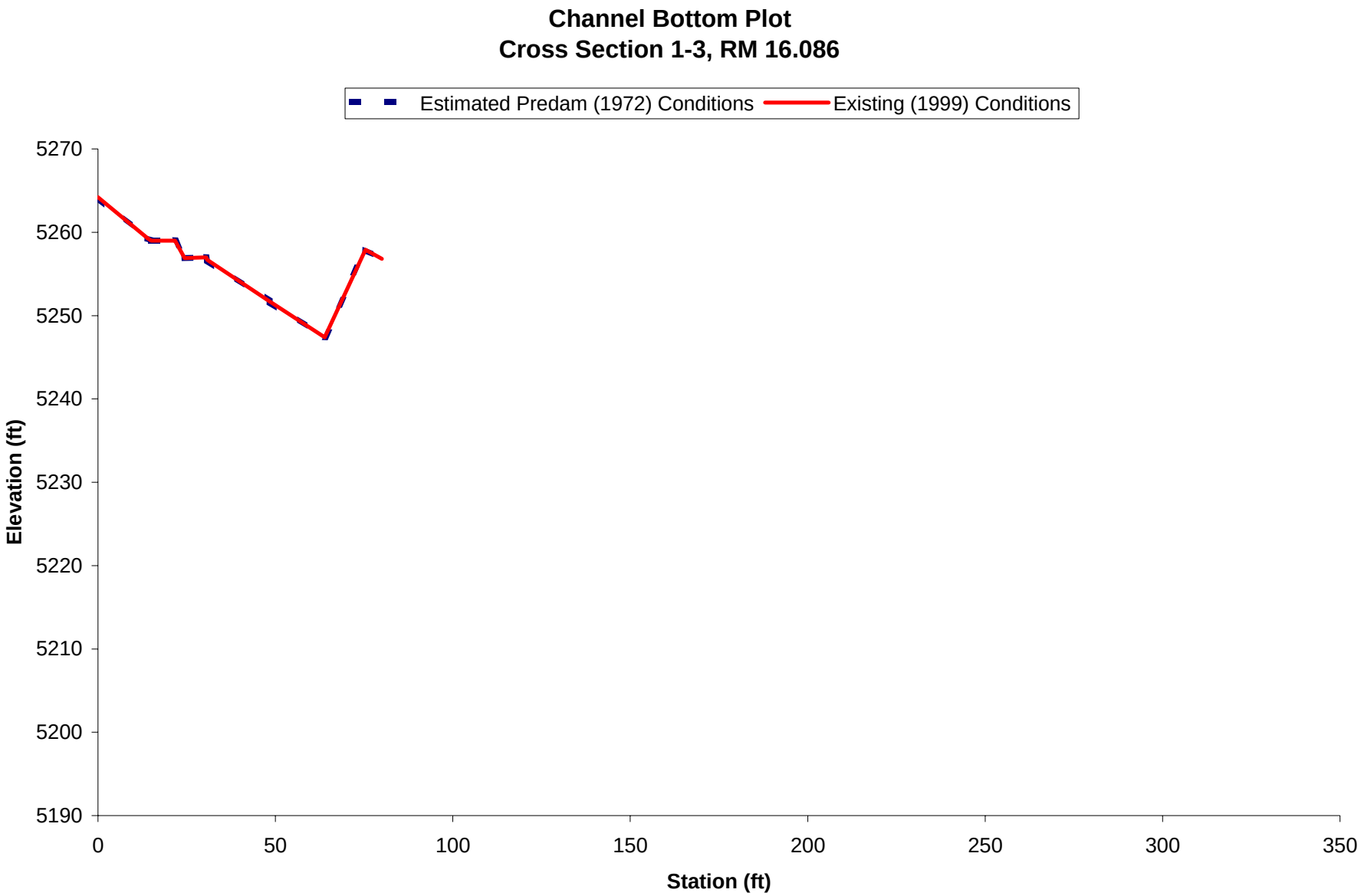
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 1-3, RM 16.086
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5230
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100
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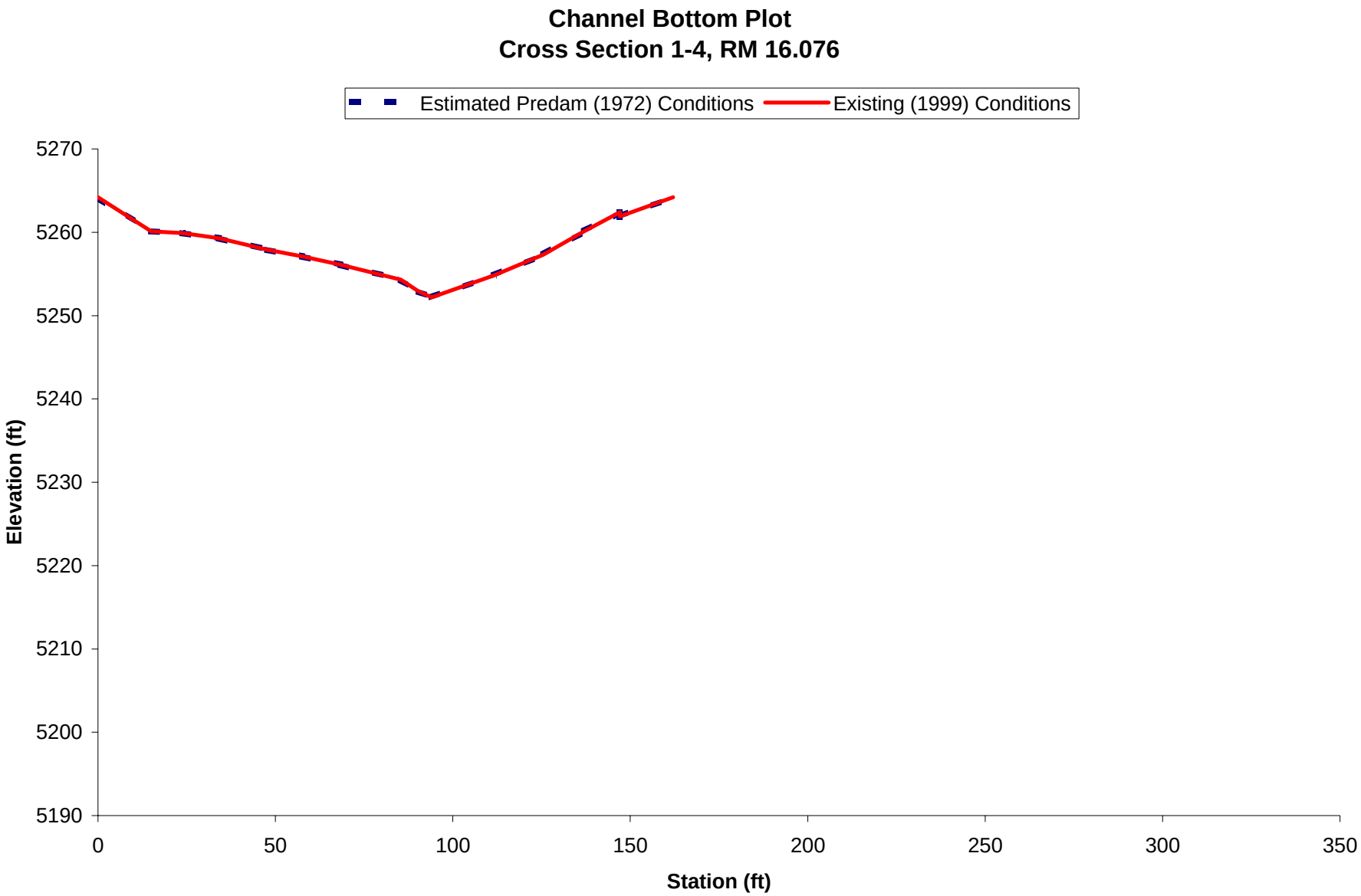
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 1-4, RM 16.076
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
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5230
5220
5210
5200
5190
0
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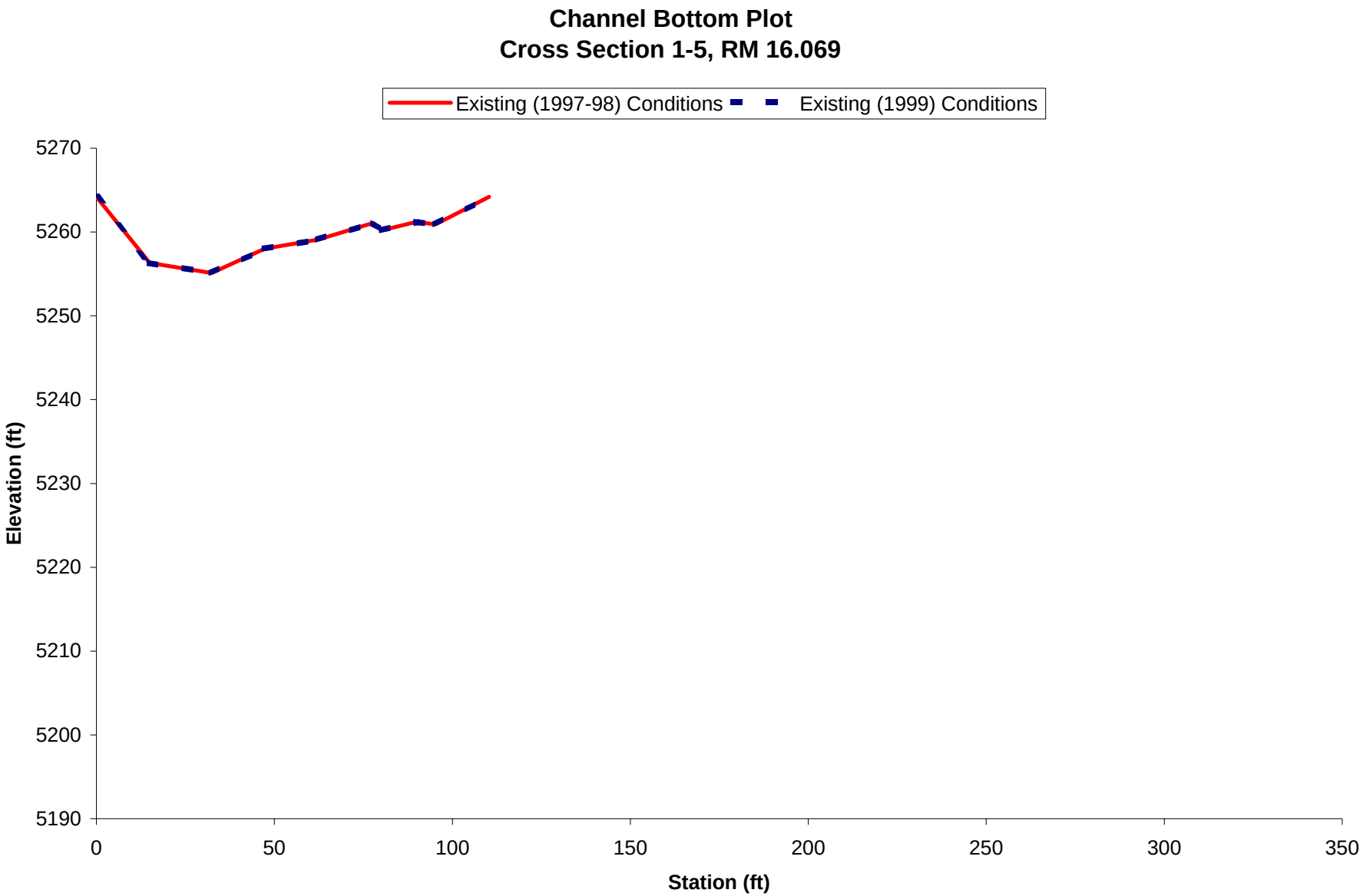
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 1-5, RM 16.069
Existing (1997-98) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
5250
5240
5230
5220
5210
5200
5190
0
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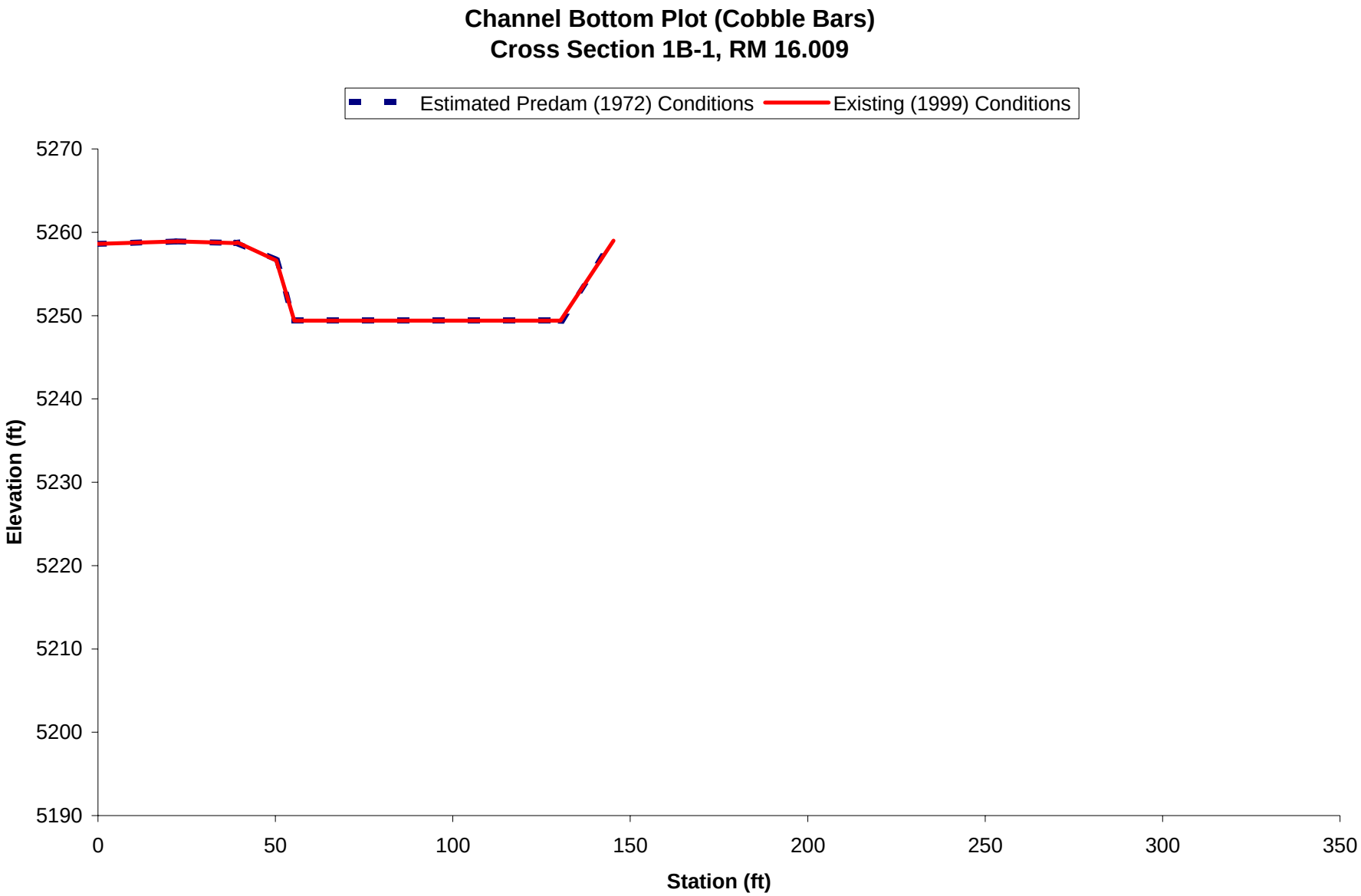
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot (Cobble Bars)
Cross Section 1B-1, RM 16.009
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5260
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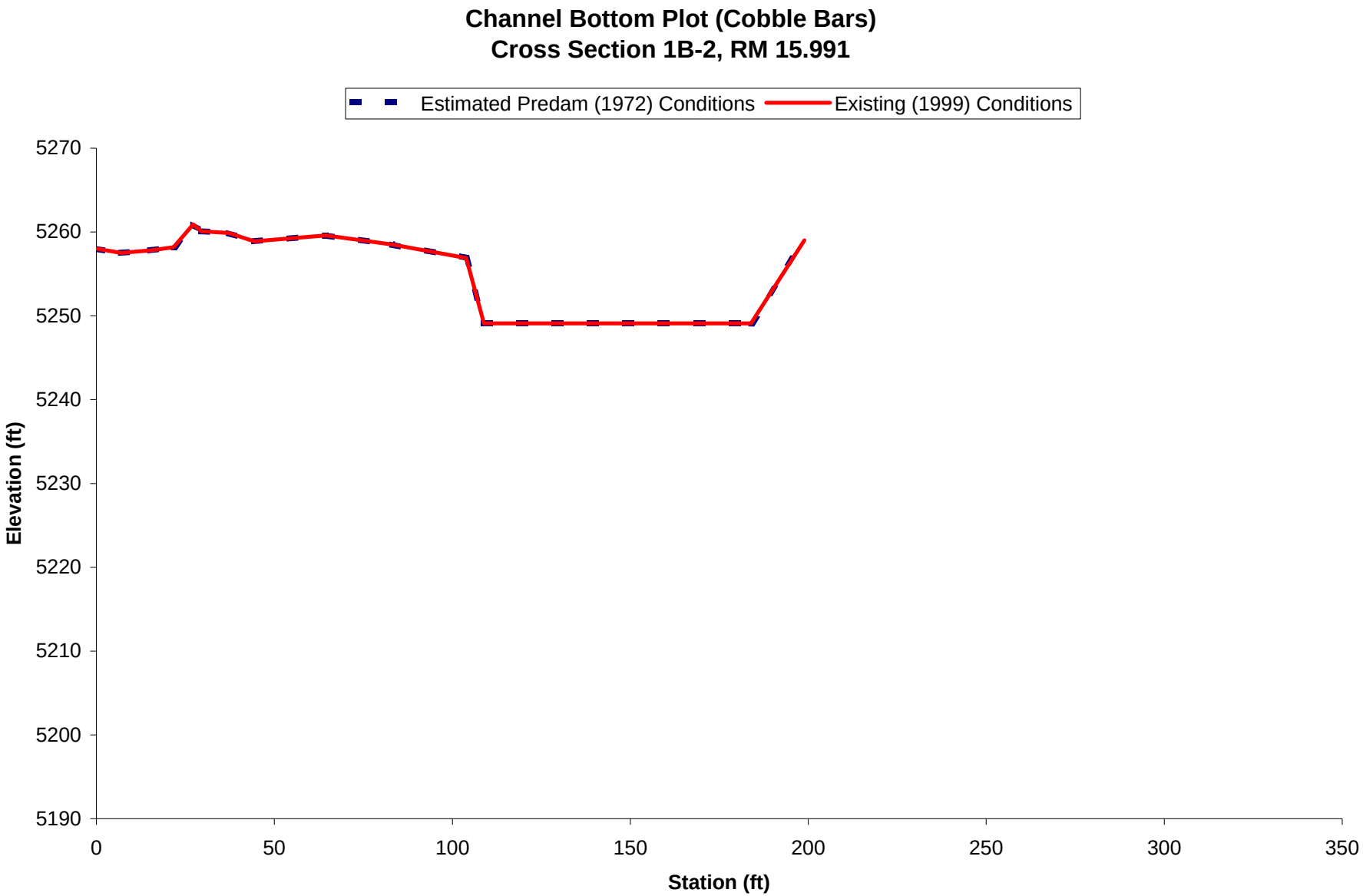
5230
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot (Cobble Bars)
Cross Section 1B-2, RM 15.991
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
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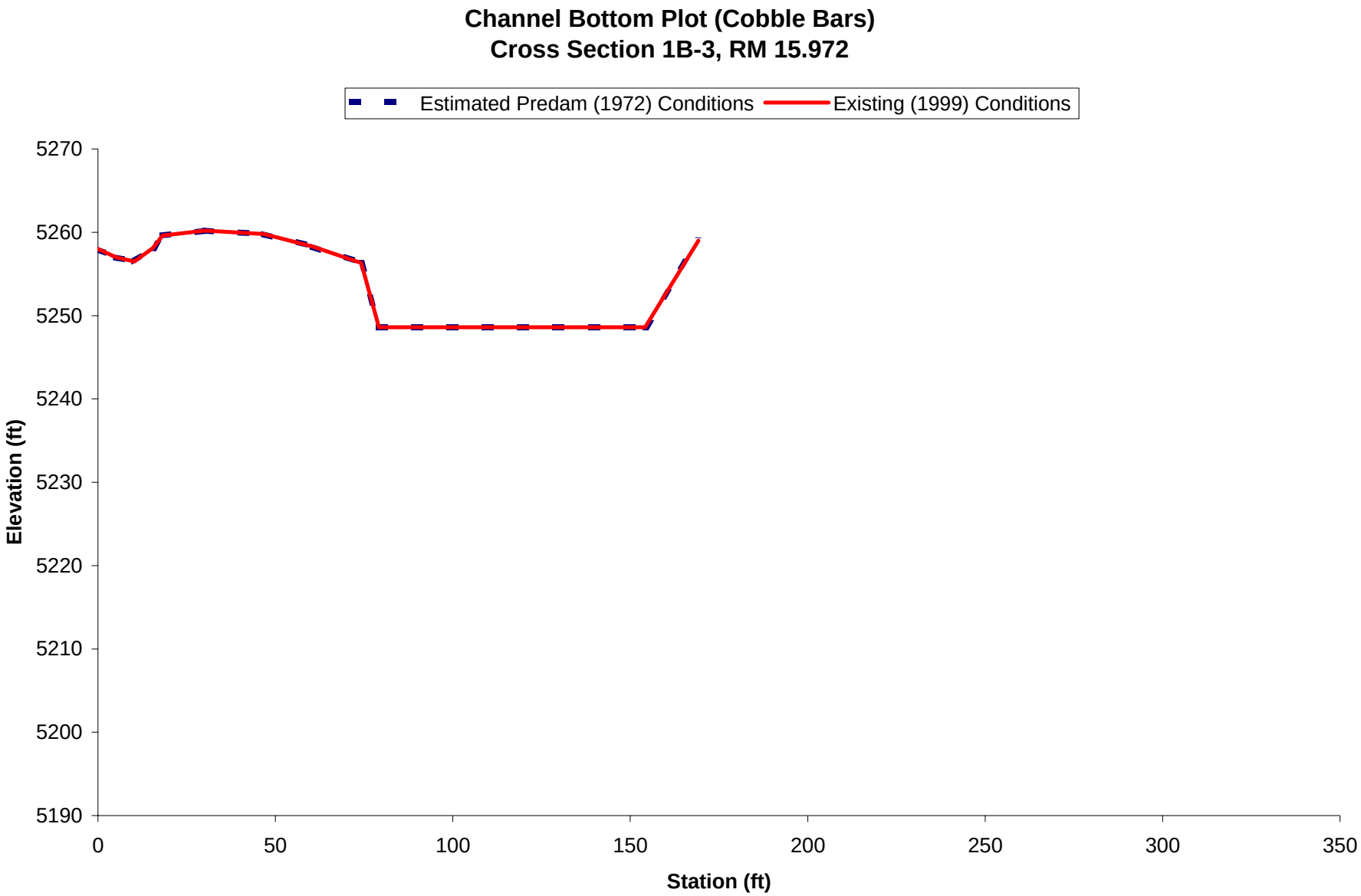
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot (Cobble Bars)
Cross Section 1B-3, RM 15.972
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5220
5210
5200
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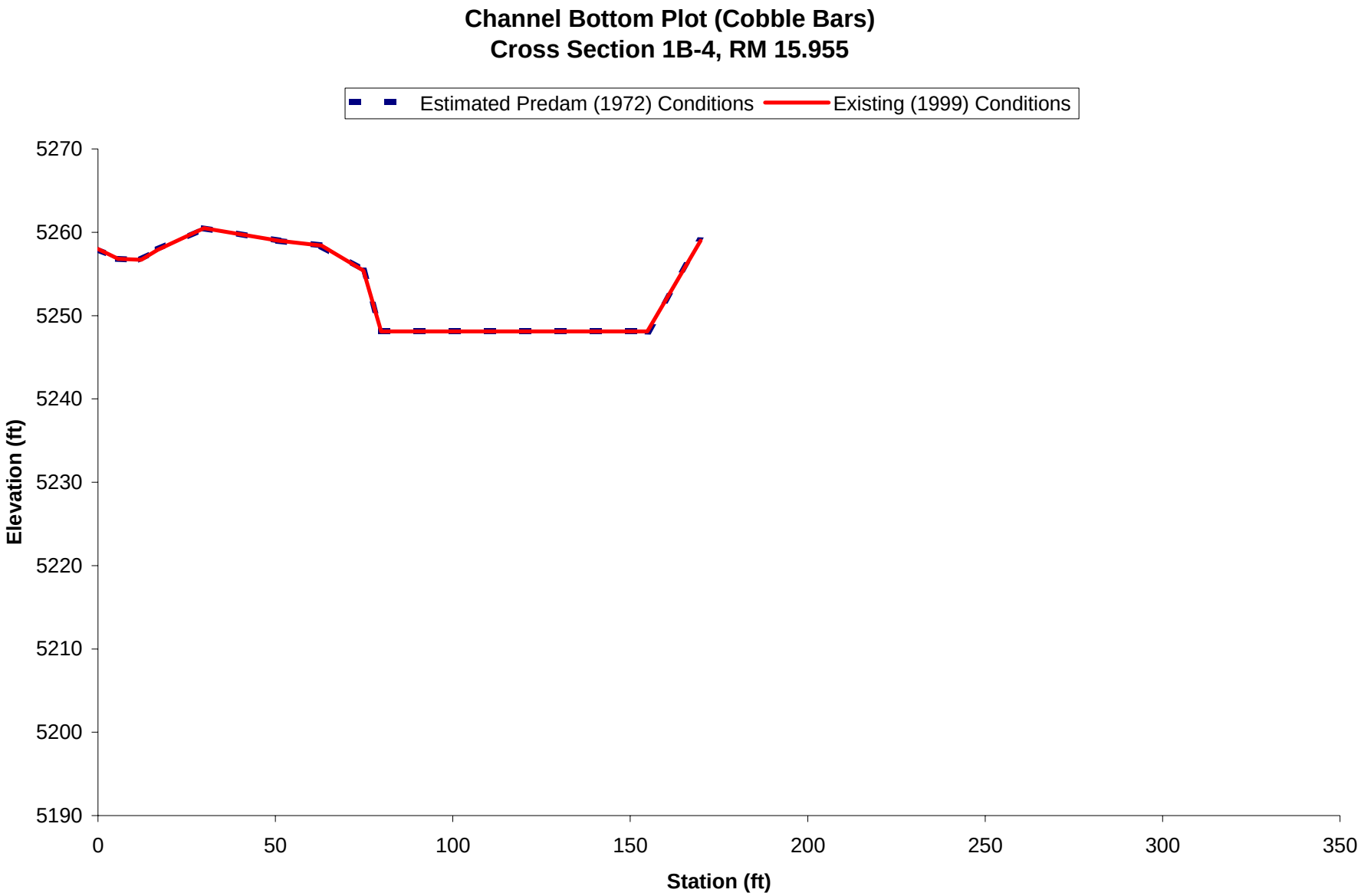
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot (Cobble Bars)
Cross Section 1B-4, RM 15.955
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5220
5210
5200
5190
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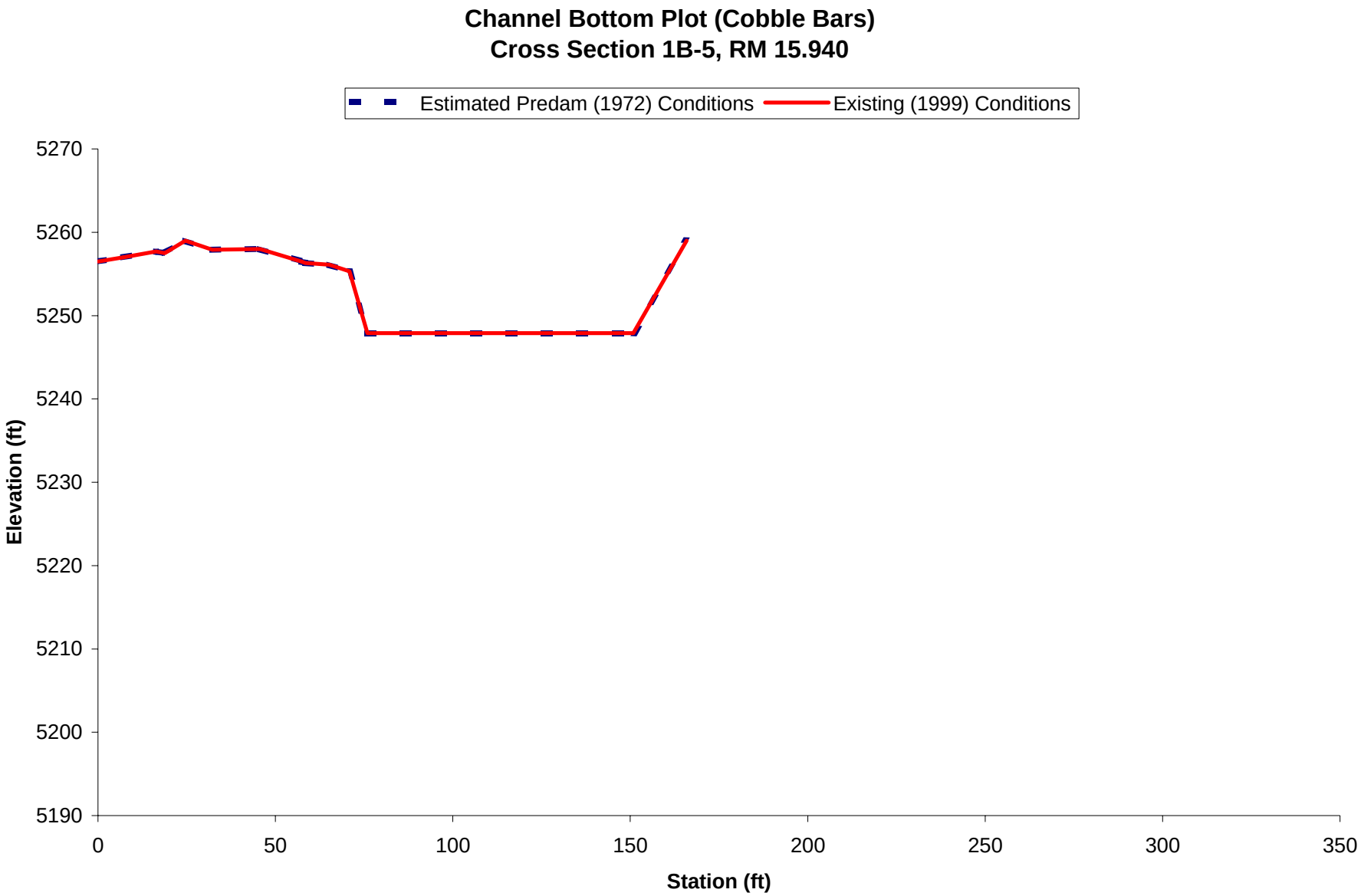
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot (Cobble Bars)
Cross Section 1B-5, RM 15.940
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5220
5210
5200
5190
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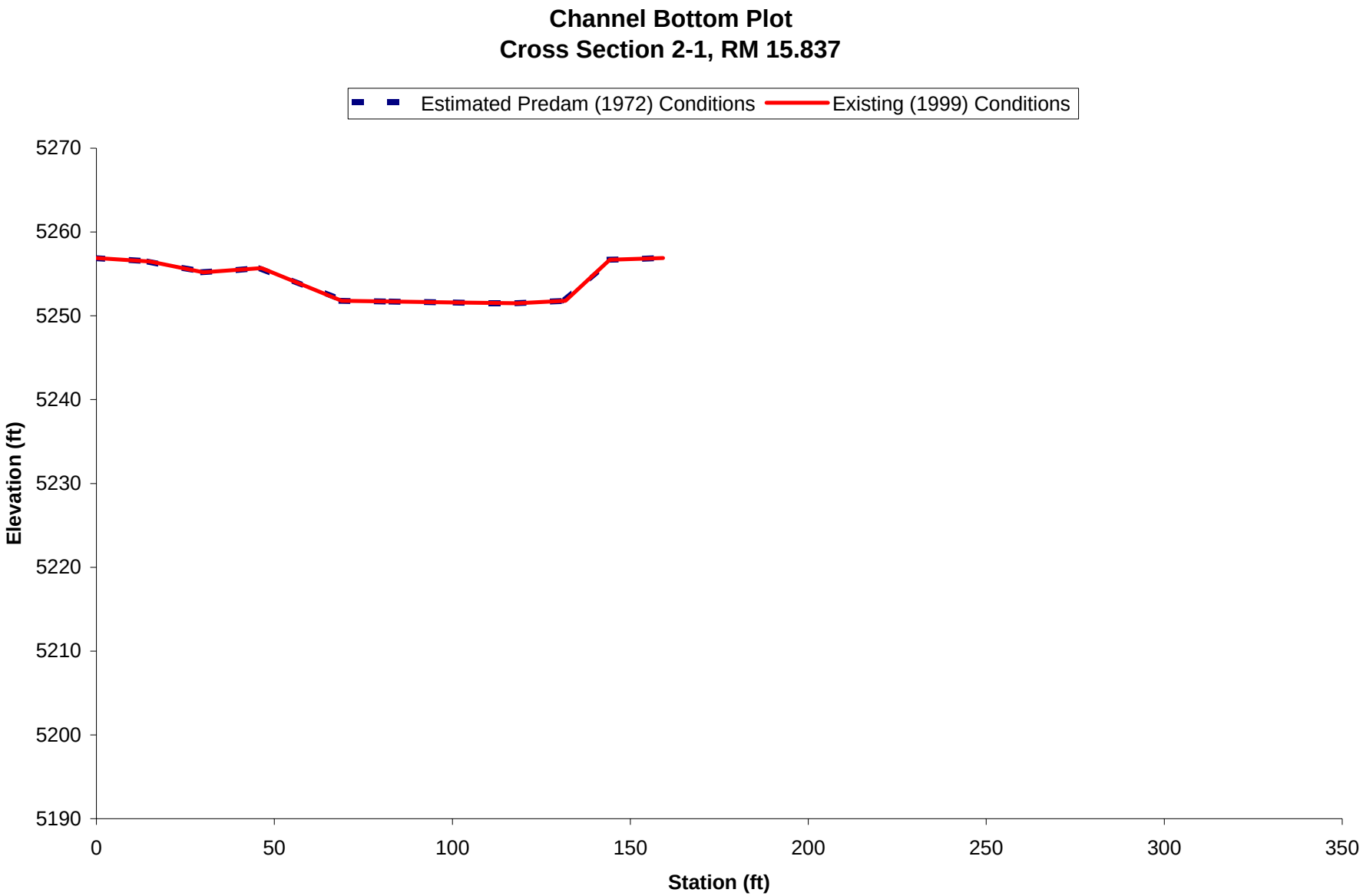
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 2-1, RM 15.837
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5220
5210
5200
5190
0
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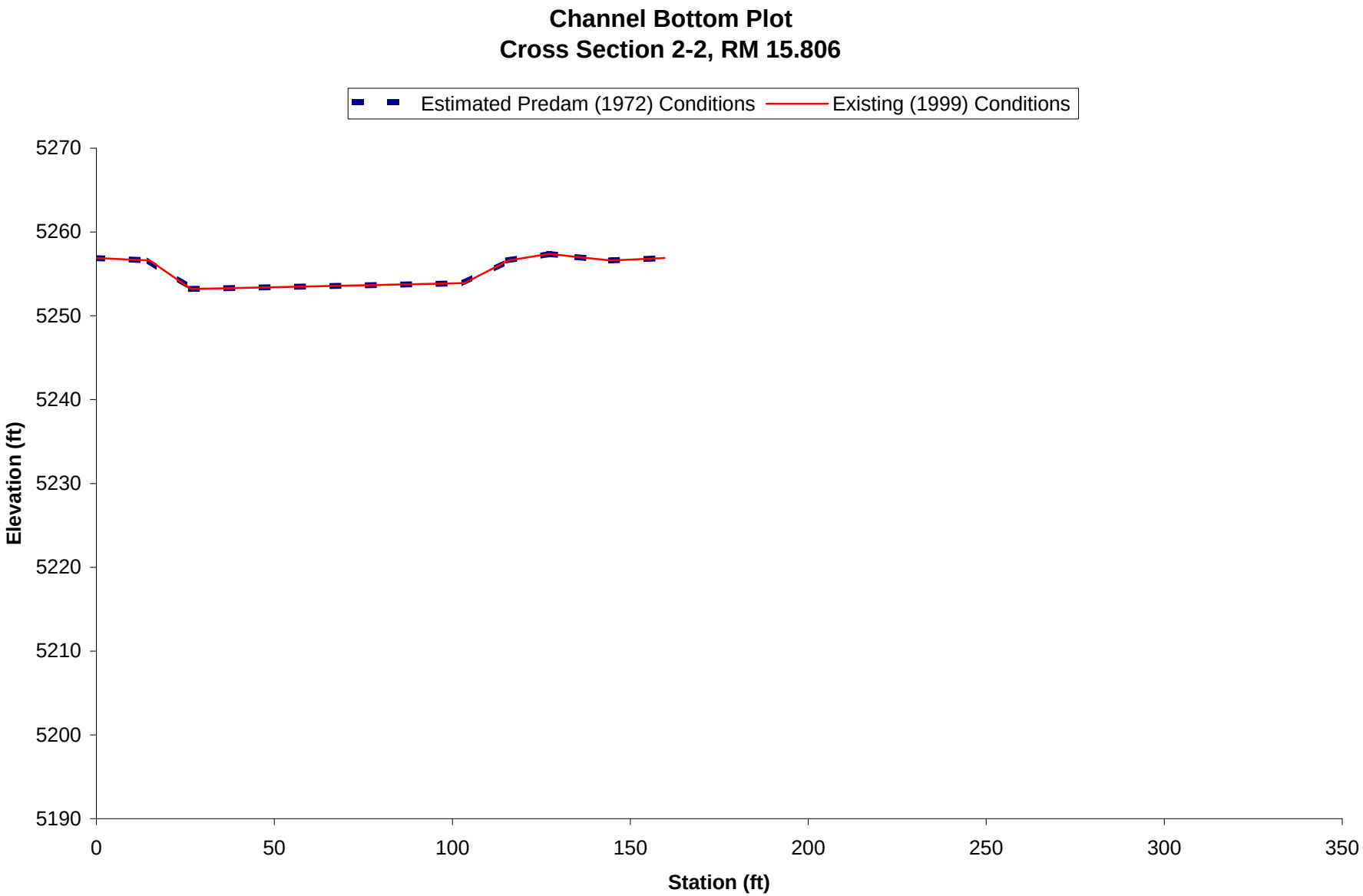
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 2-2, RM 15.806
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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300
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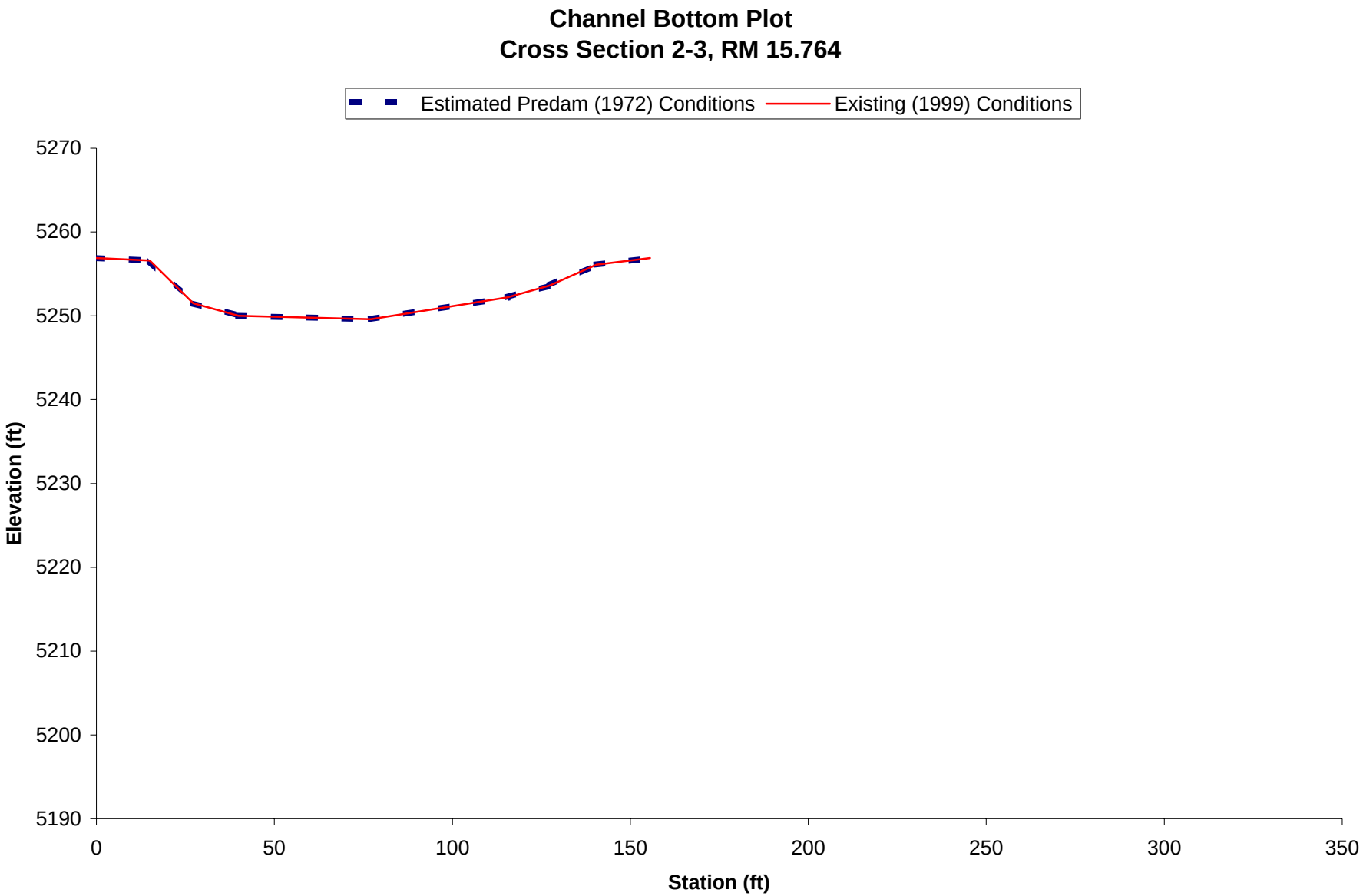
Station (ft)


Channel Bottom Plot
Cross Section 2-3, RM 15.764
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5210
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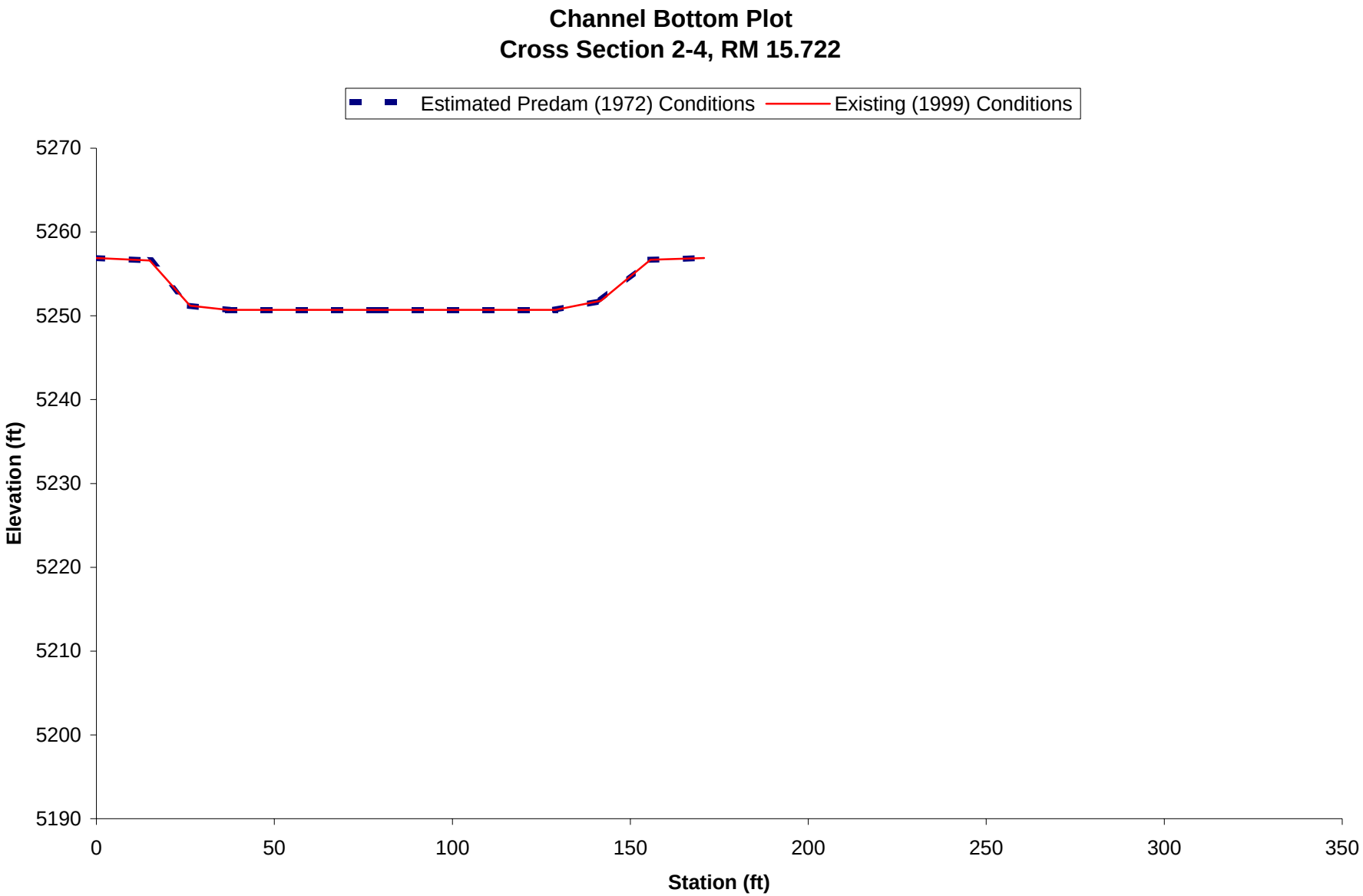
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 2-4, RM 15.722
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5200
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100
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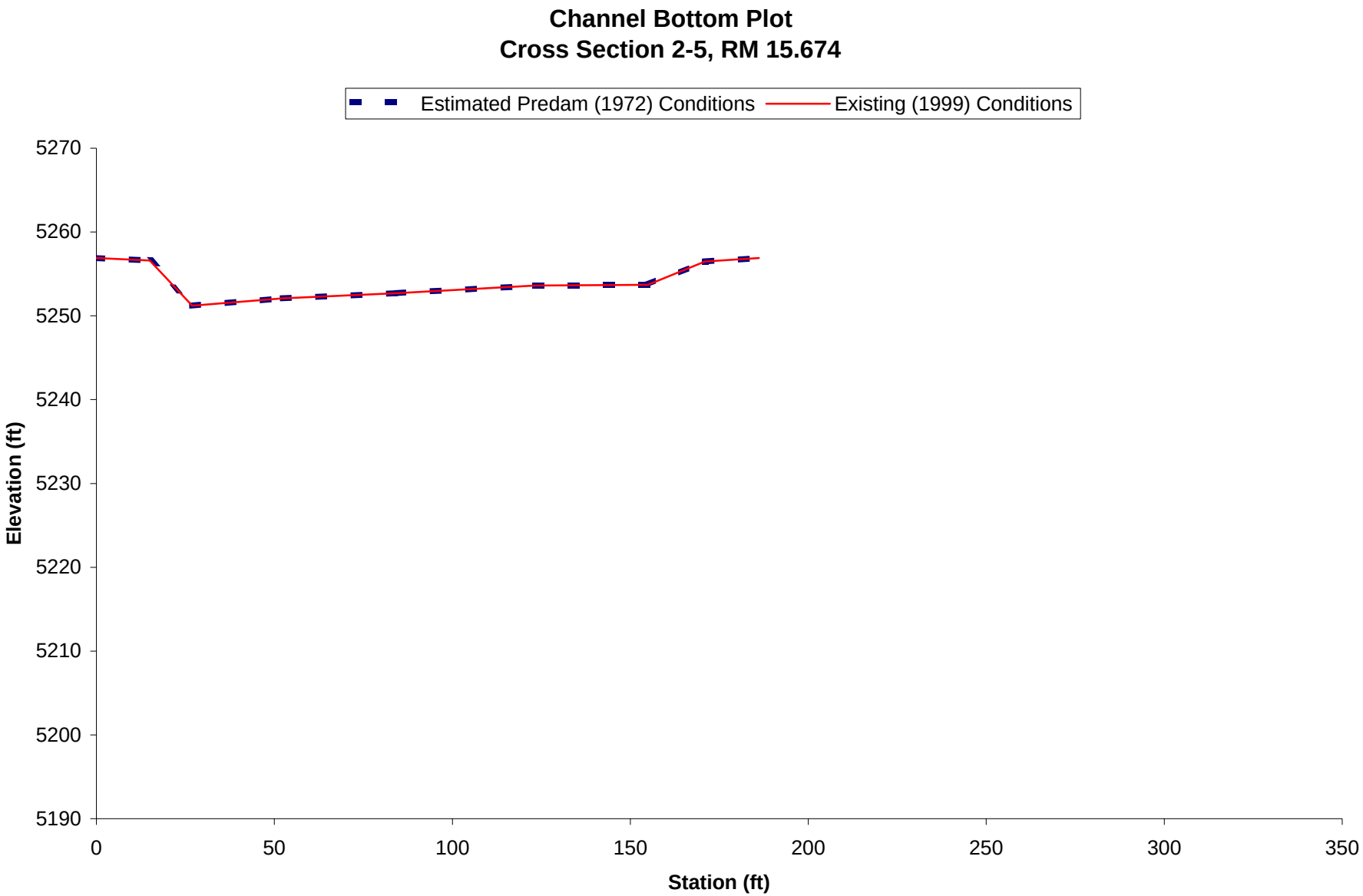
300
350
Station (ft)


Channel Bottom Plot
Cross Section 2-5, RM 15.674
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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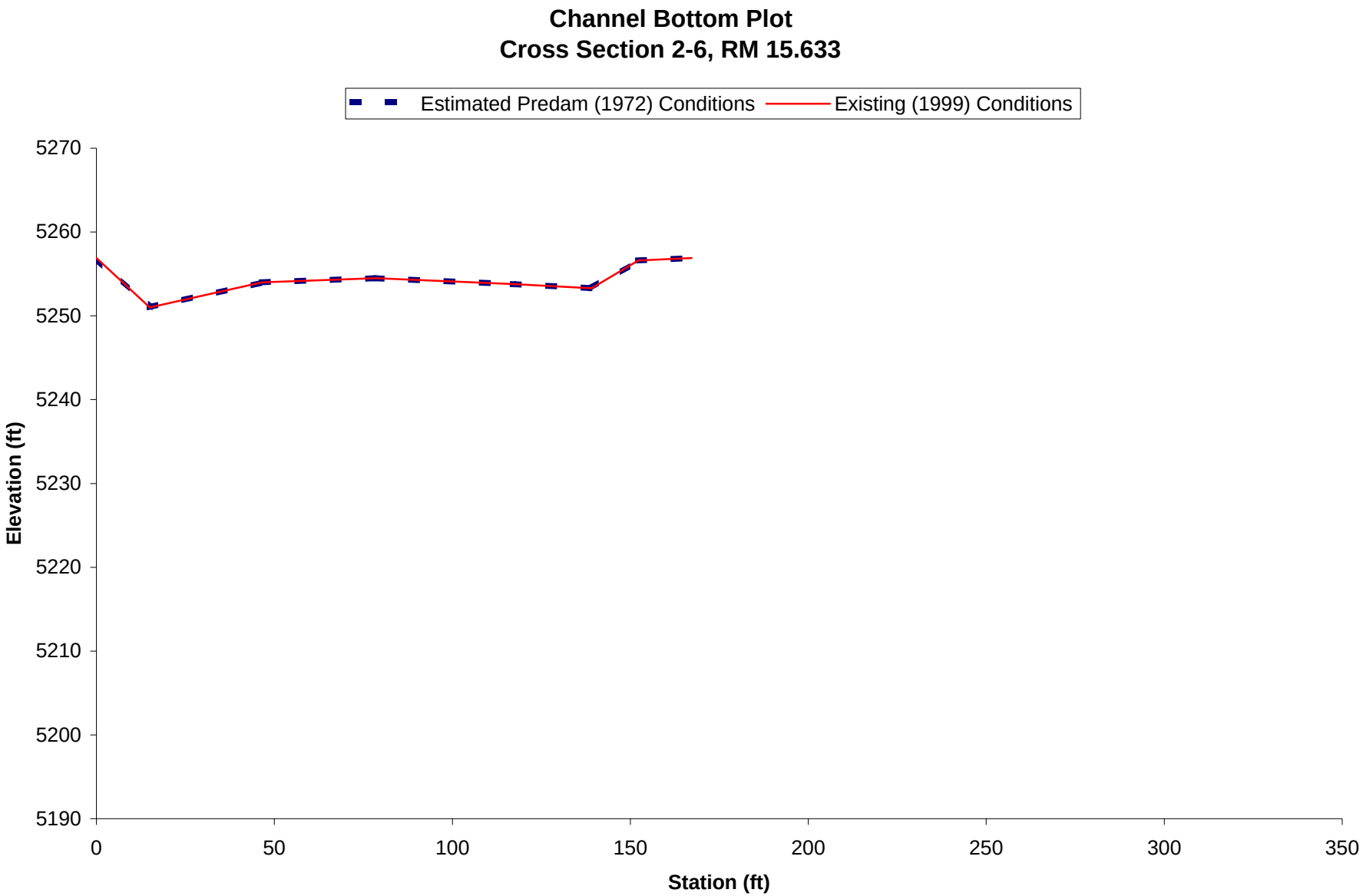
350
Station (ft)


Channel Bottom Plot
Cross Section 2-6, RM 15.633
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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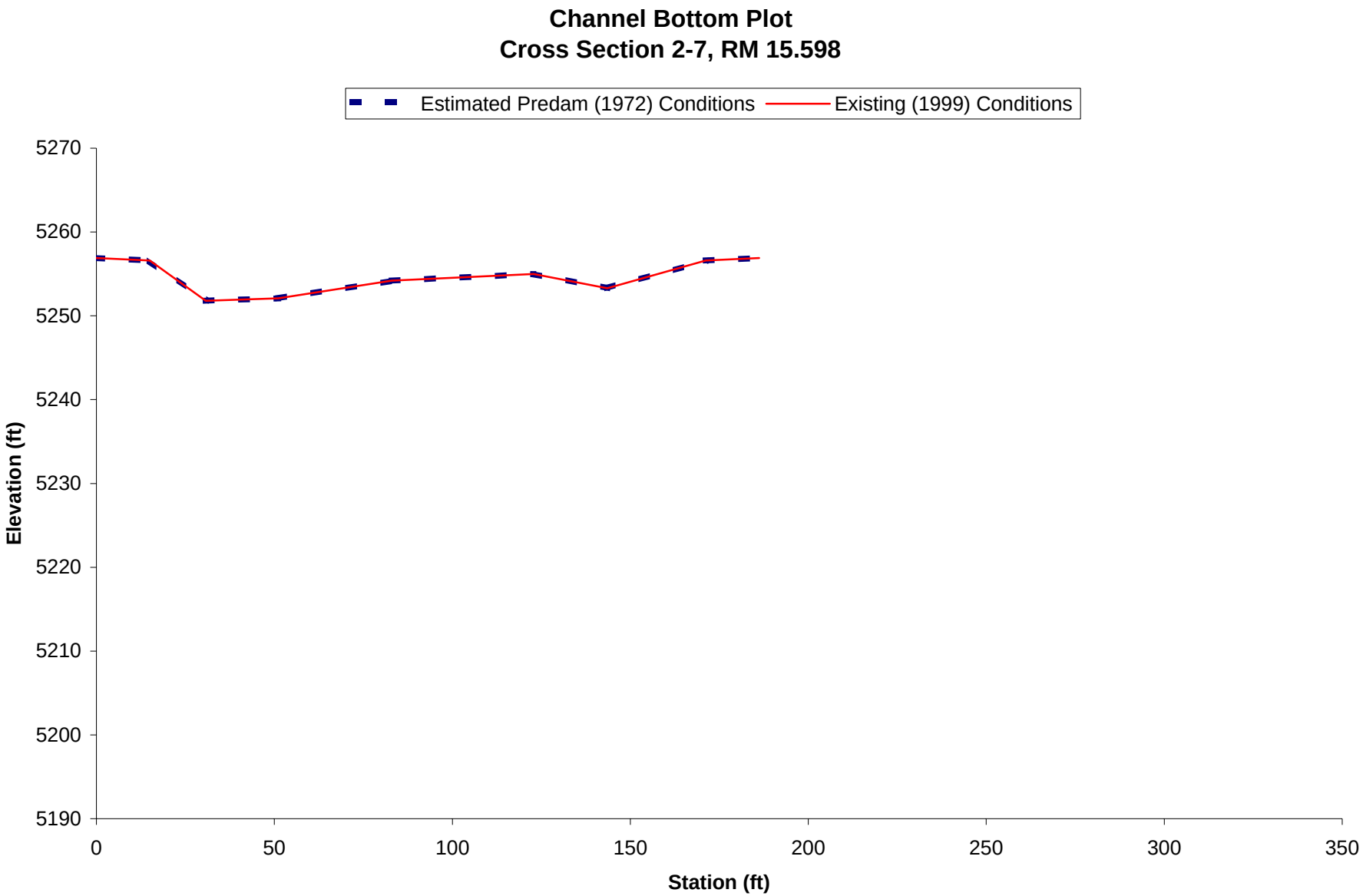
350
Station (ft)


Channel Bottom Plot
Cross Section 2-7, RM 15.598
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5230
5220
5210
5200
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100
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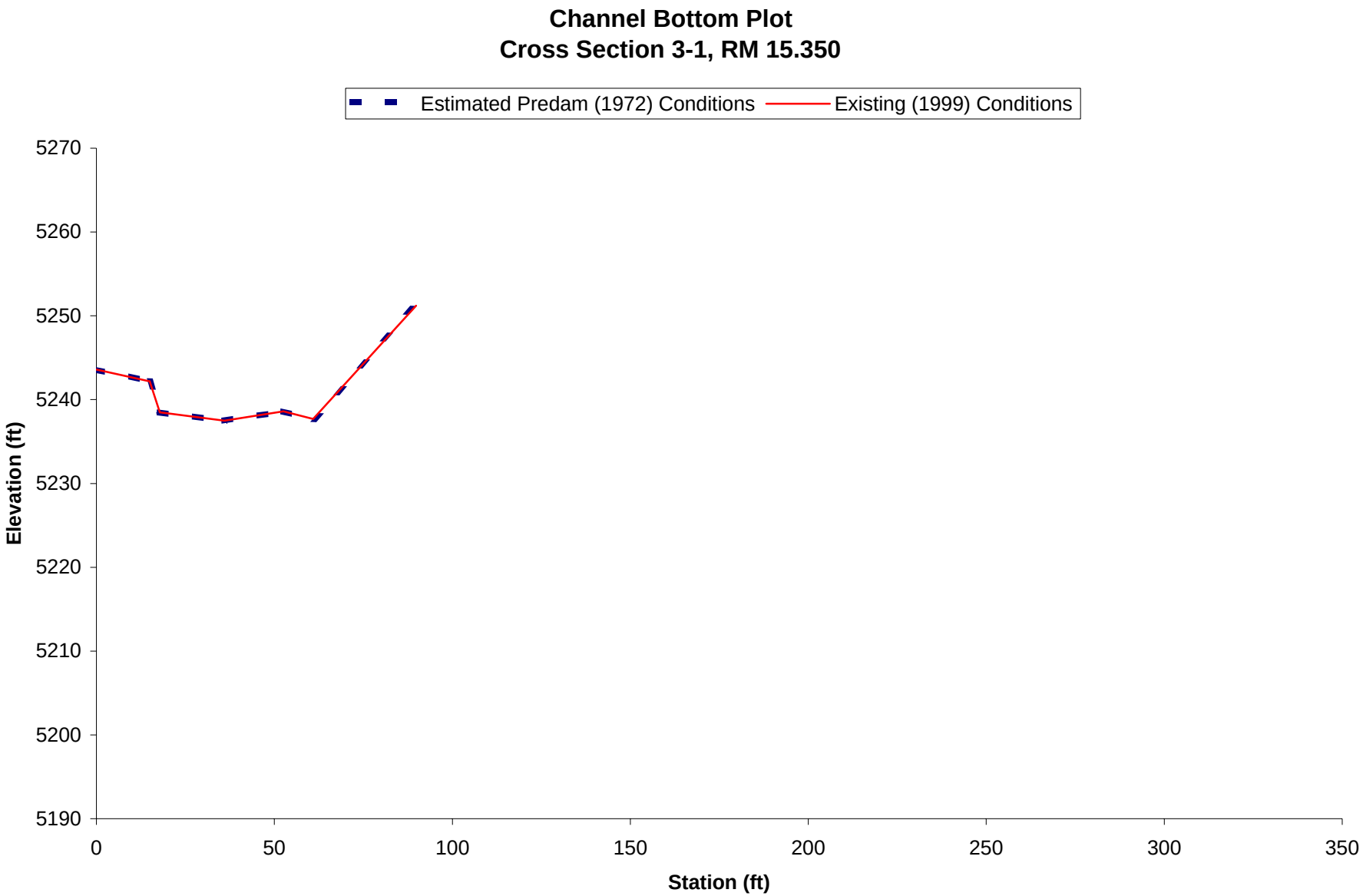
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 3-1, RM 15.350
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5230
5220
5210
5200
5190
0
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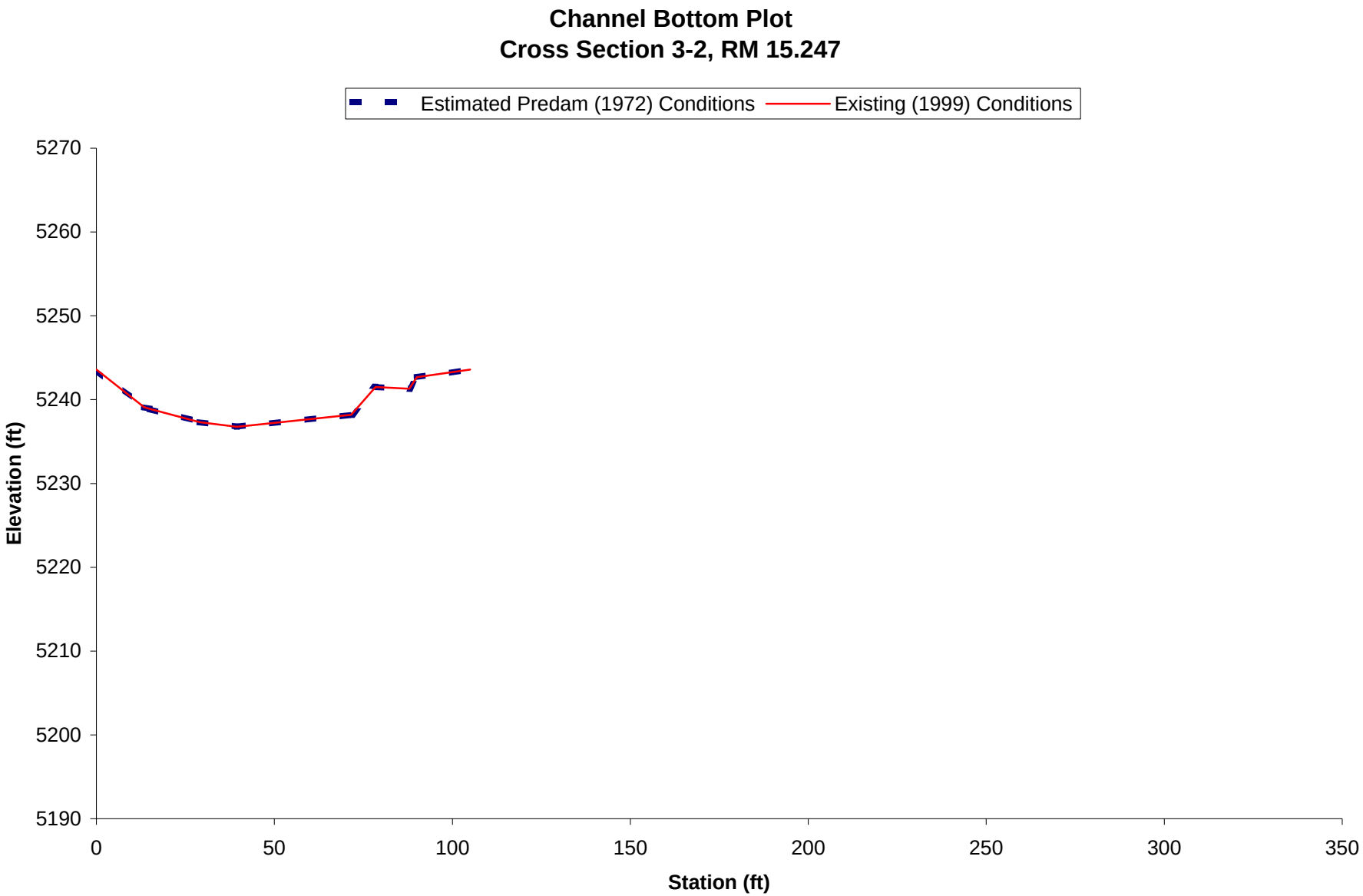
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 3-2, RM 15.247
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5250
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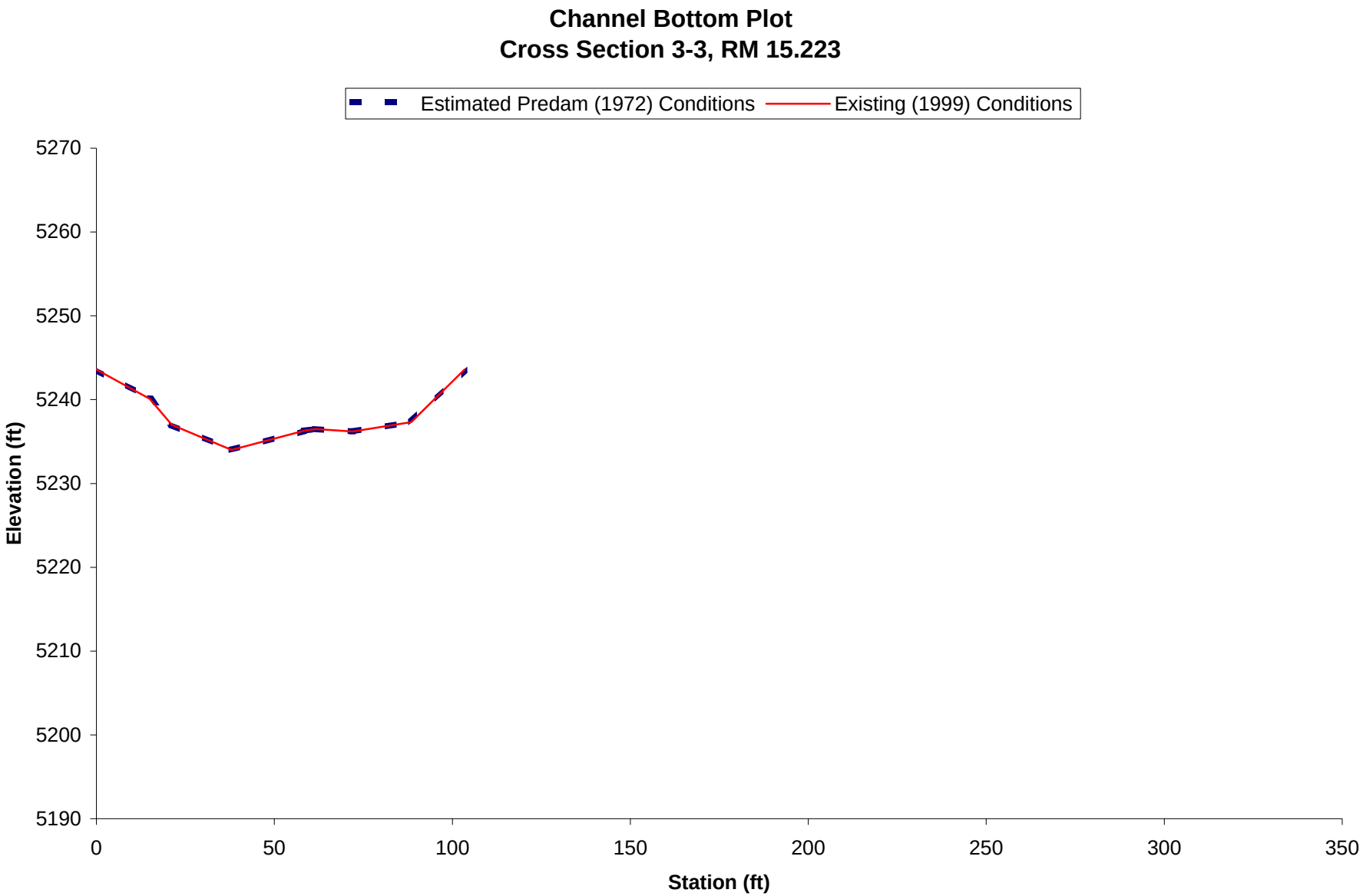
5230
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 3-3, RM 15.223
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5210
5200
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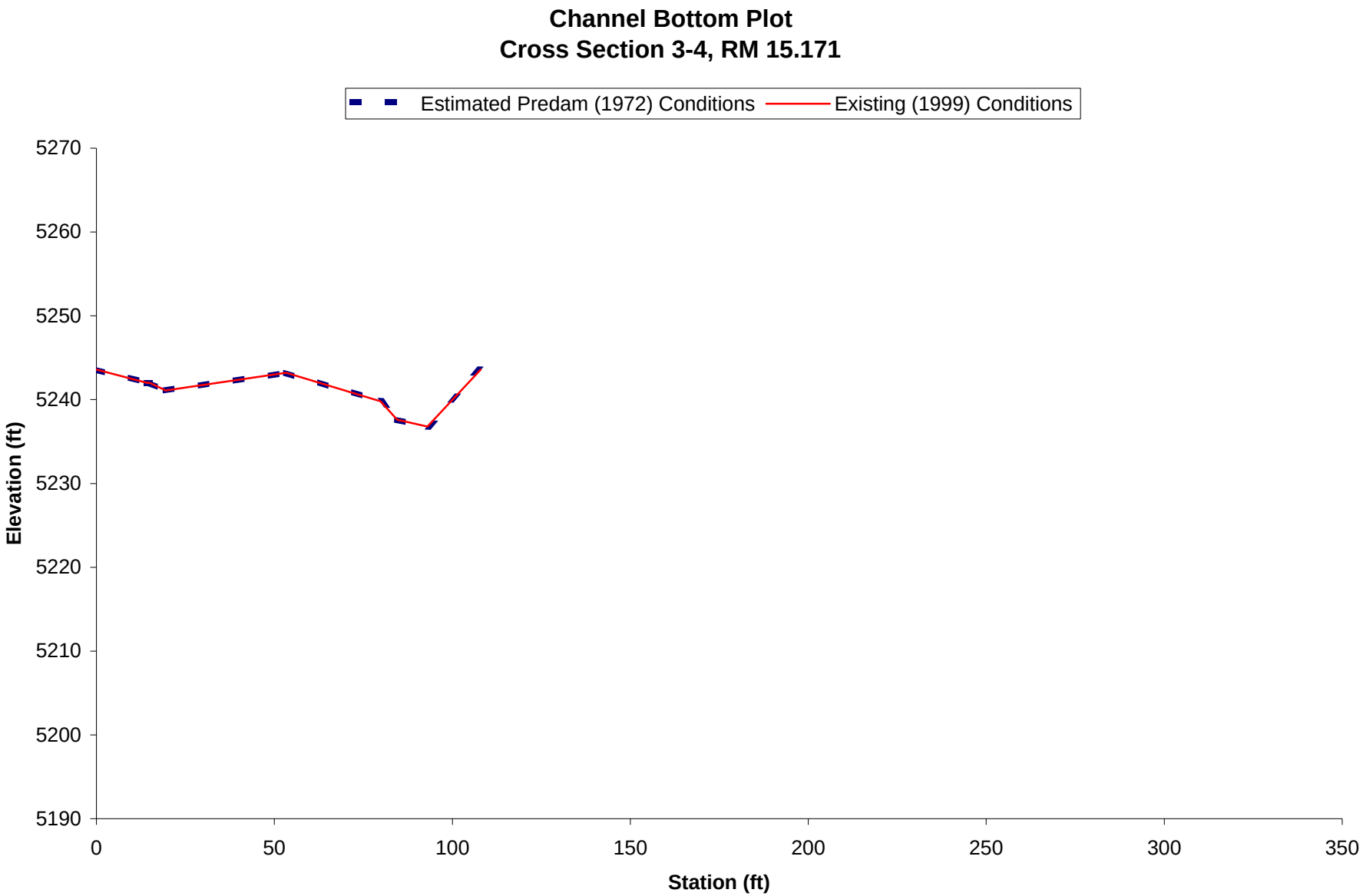
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 3-4, RM 15.171
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5210
5200
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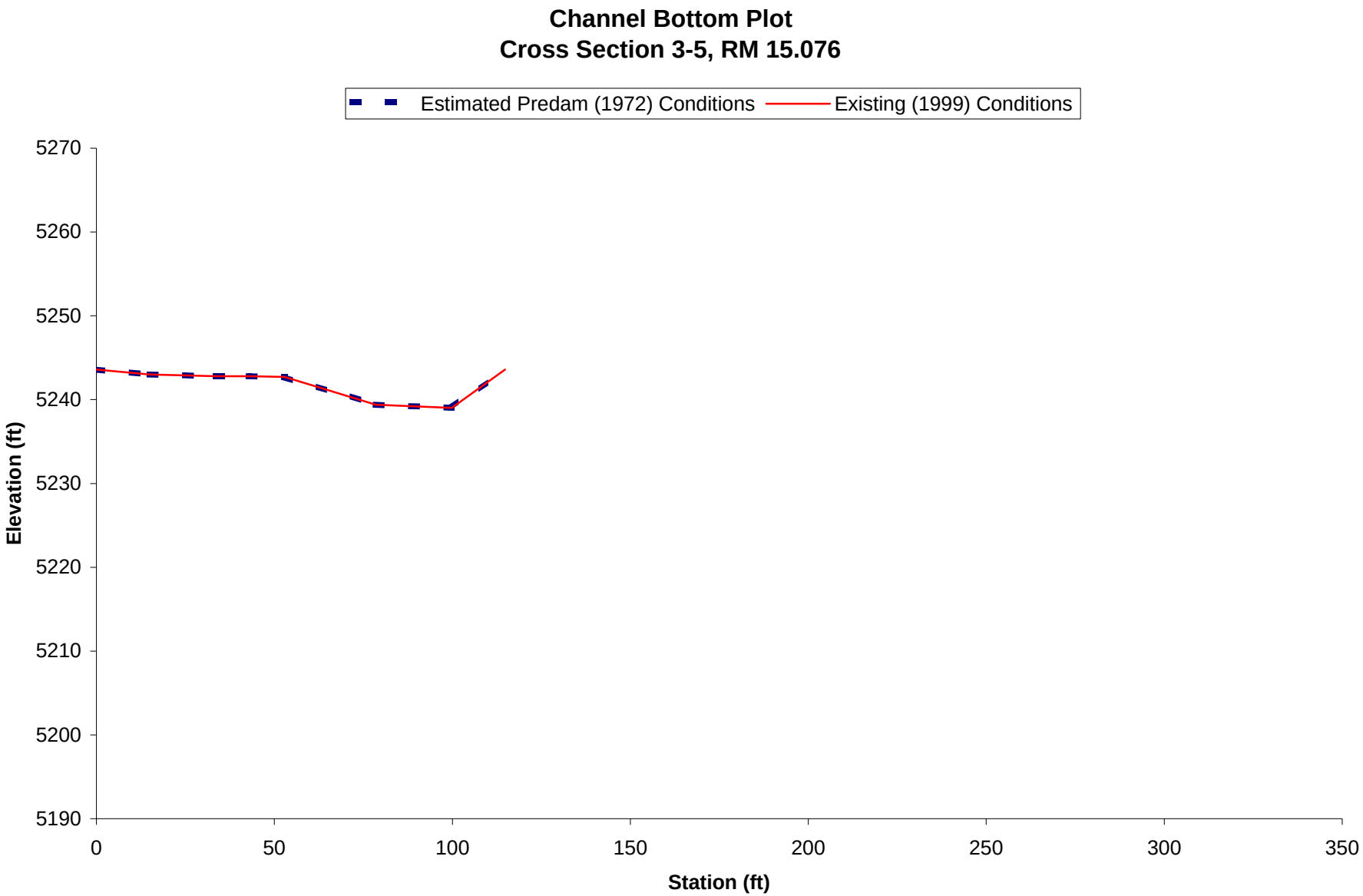
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 3-5, RM 15.076
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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300
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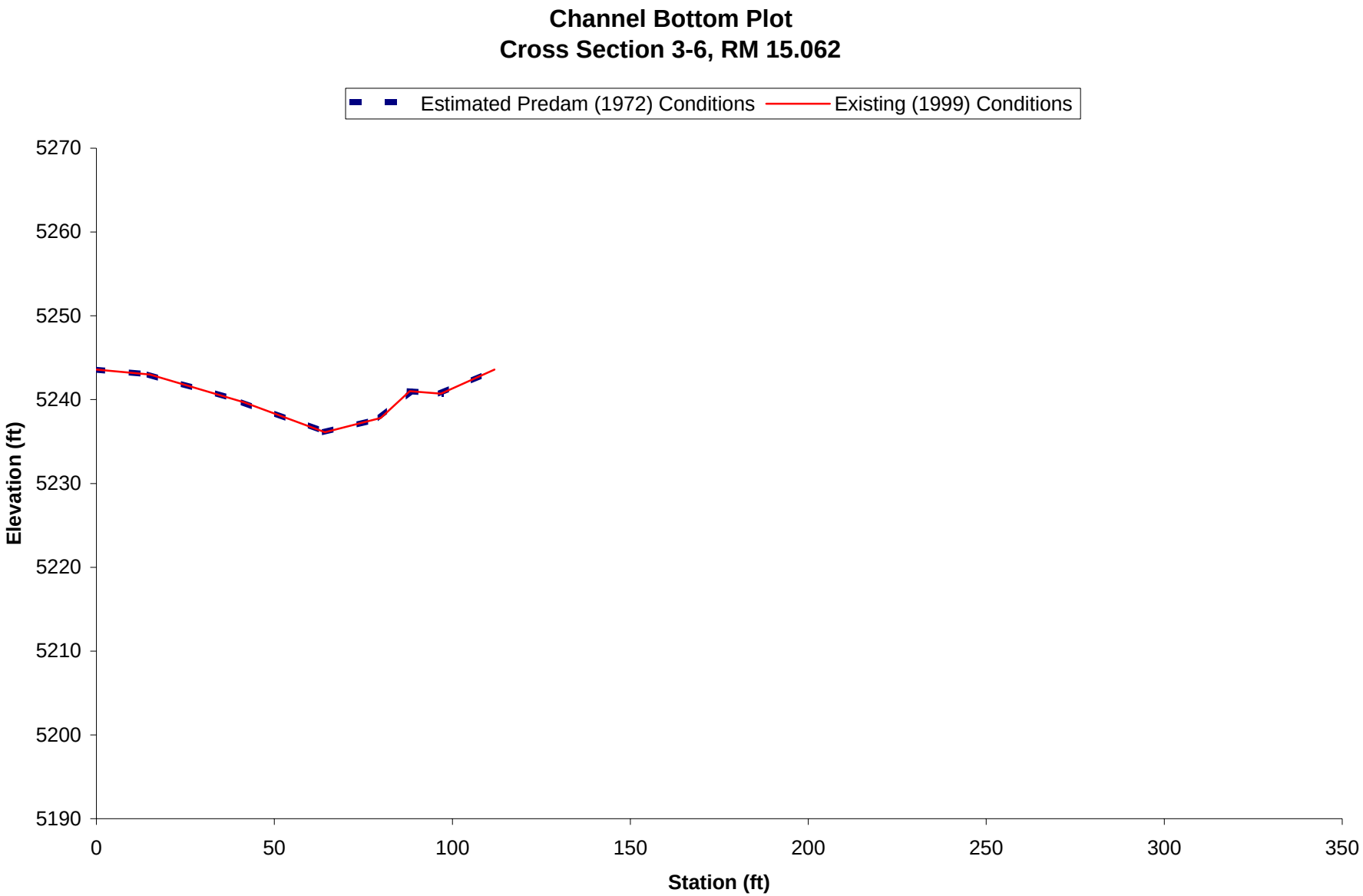
Station (ft)


Channel Bottom Plot
Cross Section 3-6, RM 15.062
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Existing (1999) Conditions
Elevation (ft)
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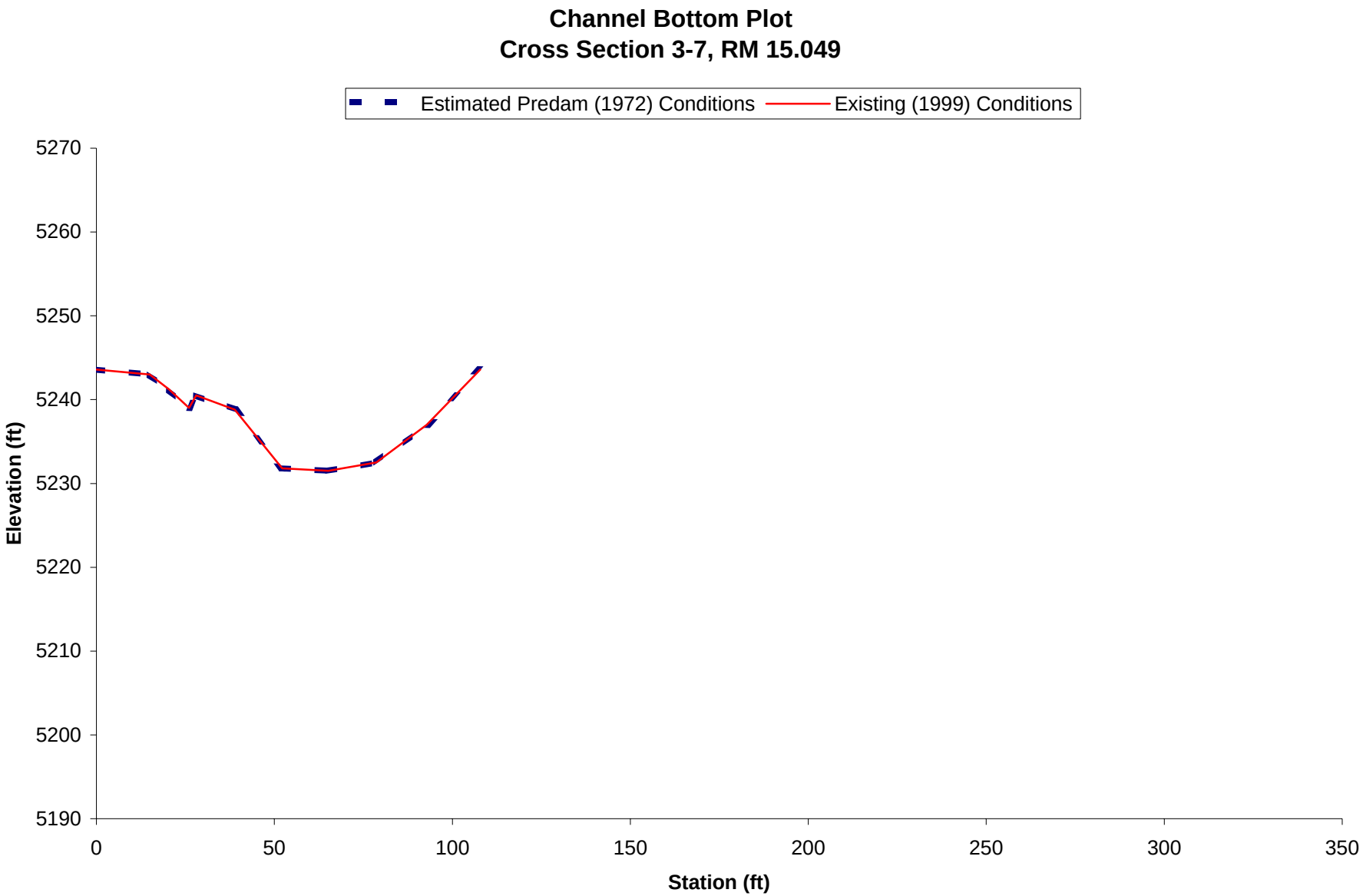
Station (ft)


Channel Bottom Plot
Cross Section 3-7, RM 15.049
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5200
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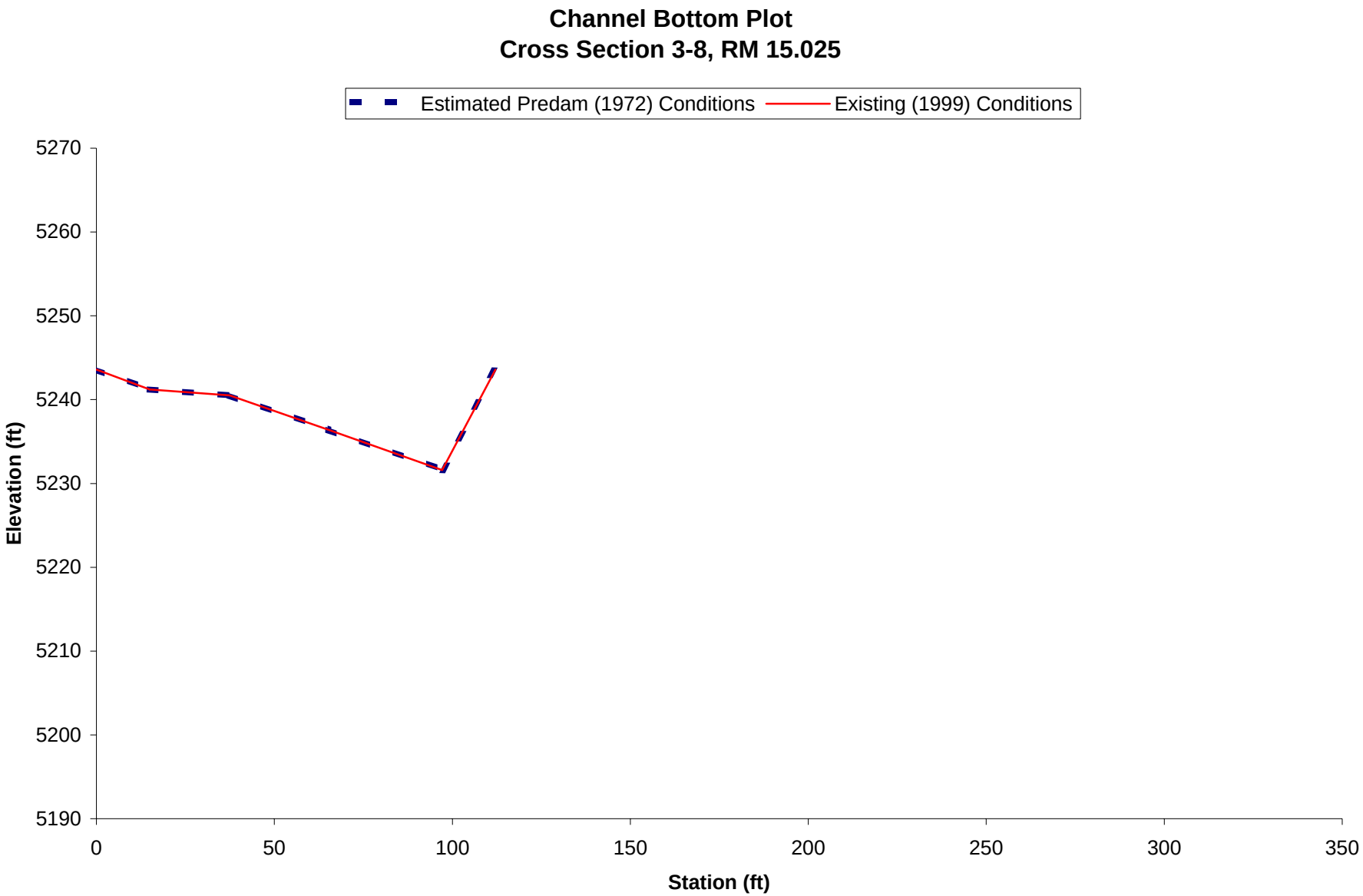
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 3-8, RM 15.025
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5200
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100
150
200
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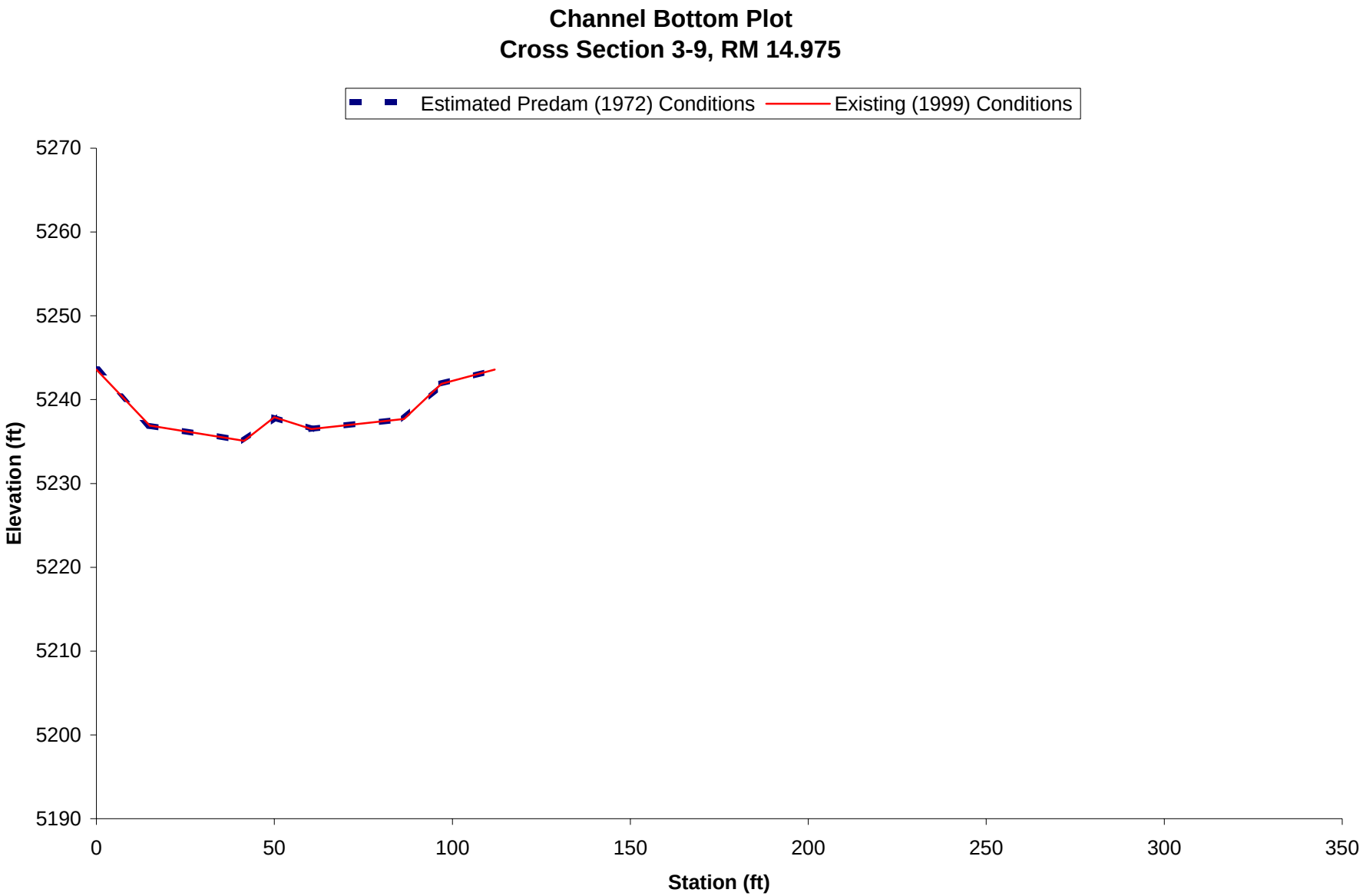
300
350
Station (ft)


Channel Bottom Plot
Cross Section 3-9, RM 14.975
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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100
150
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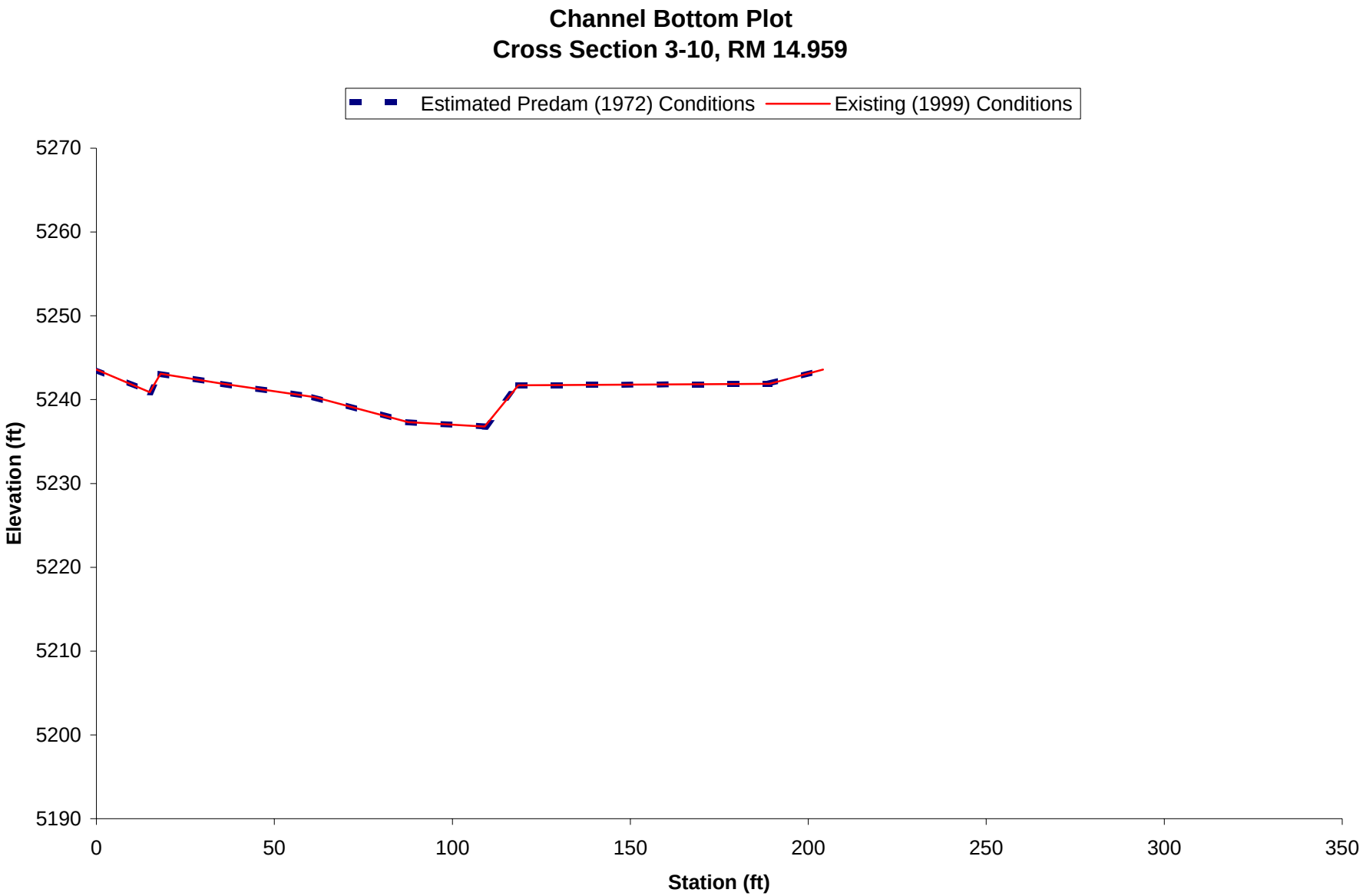
300
350
Station (ft)


Channel Bottom Plot
Cross Section 3-10, RM 14.959
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5200
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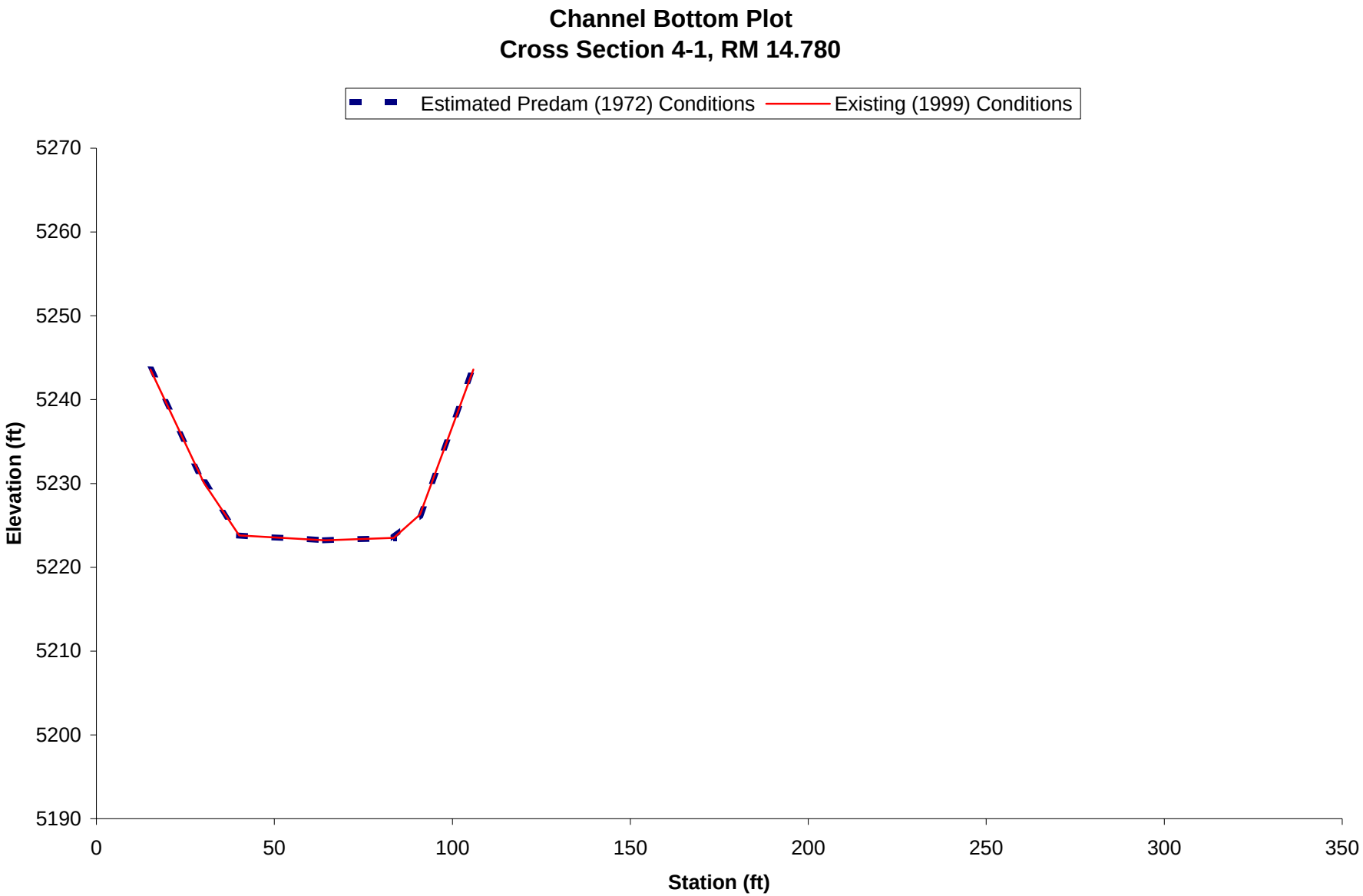
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-1, RM 14.780
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5220
5210
5200
5190
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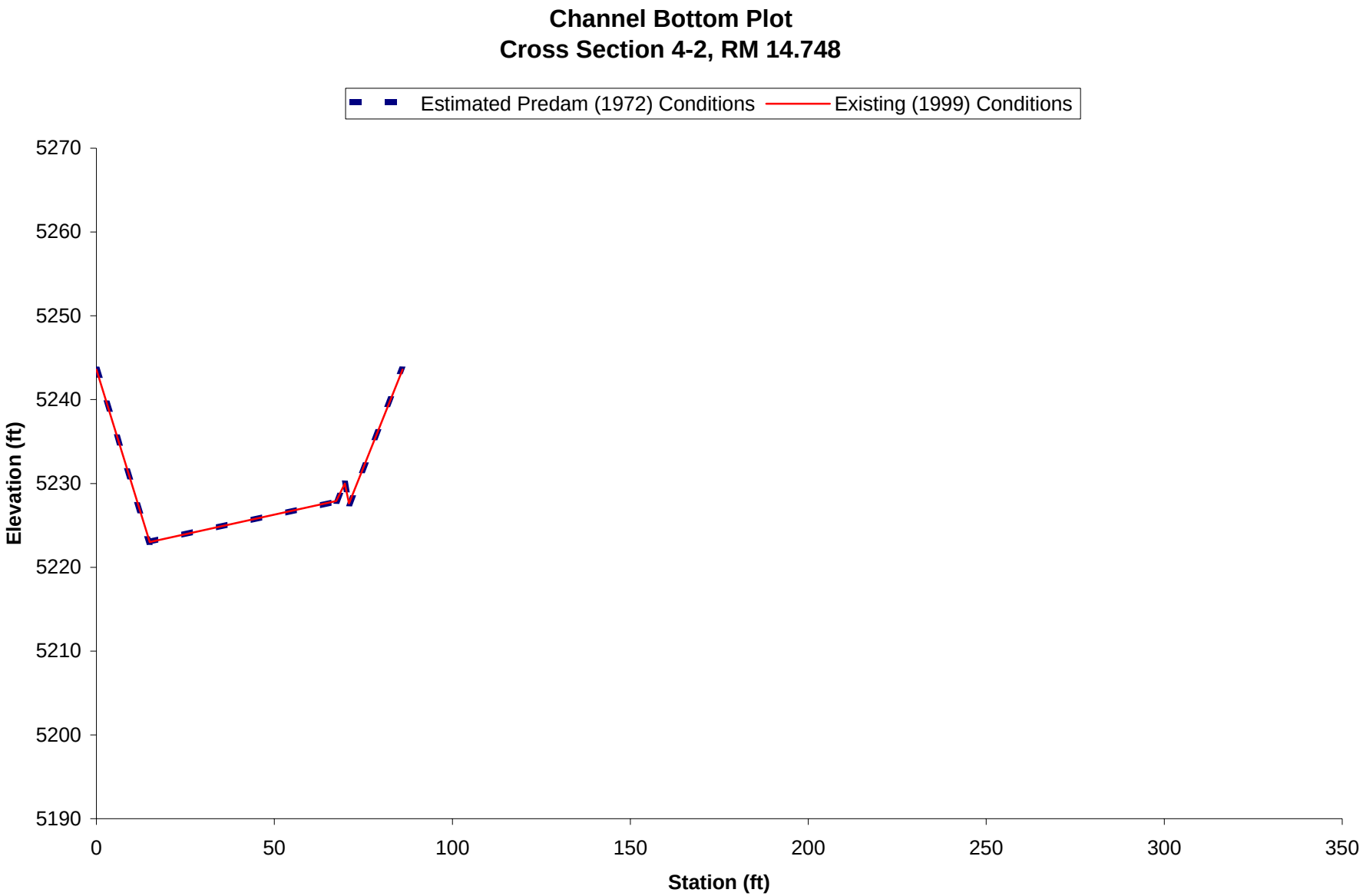
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-2, RM 14.748
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5220
5210
5200
5190
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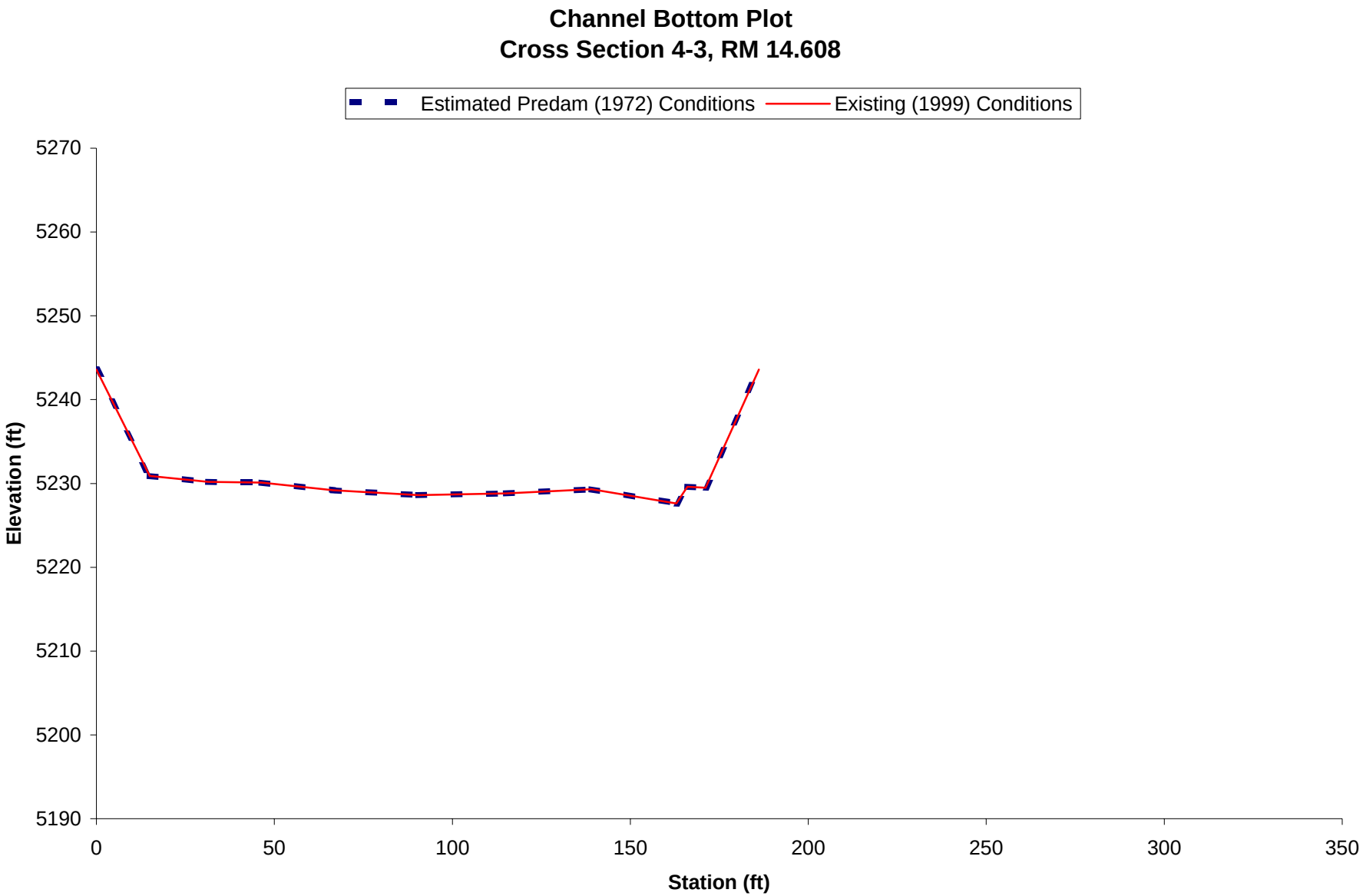
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-3, RM 14.608
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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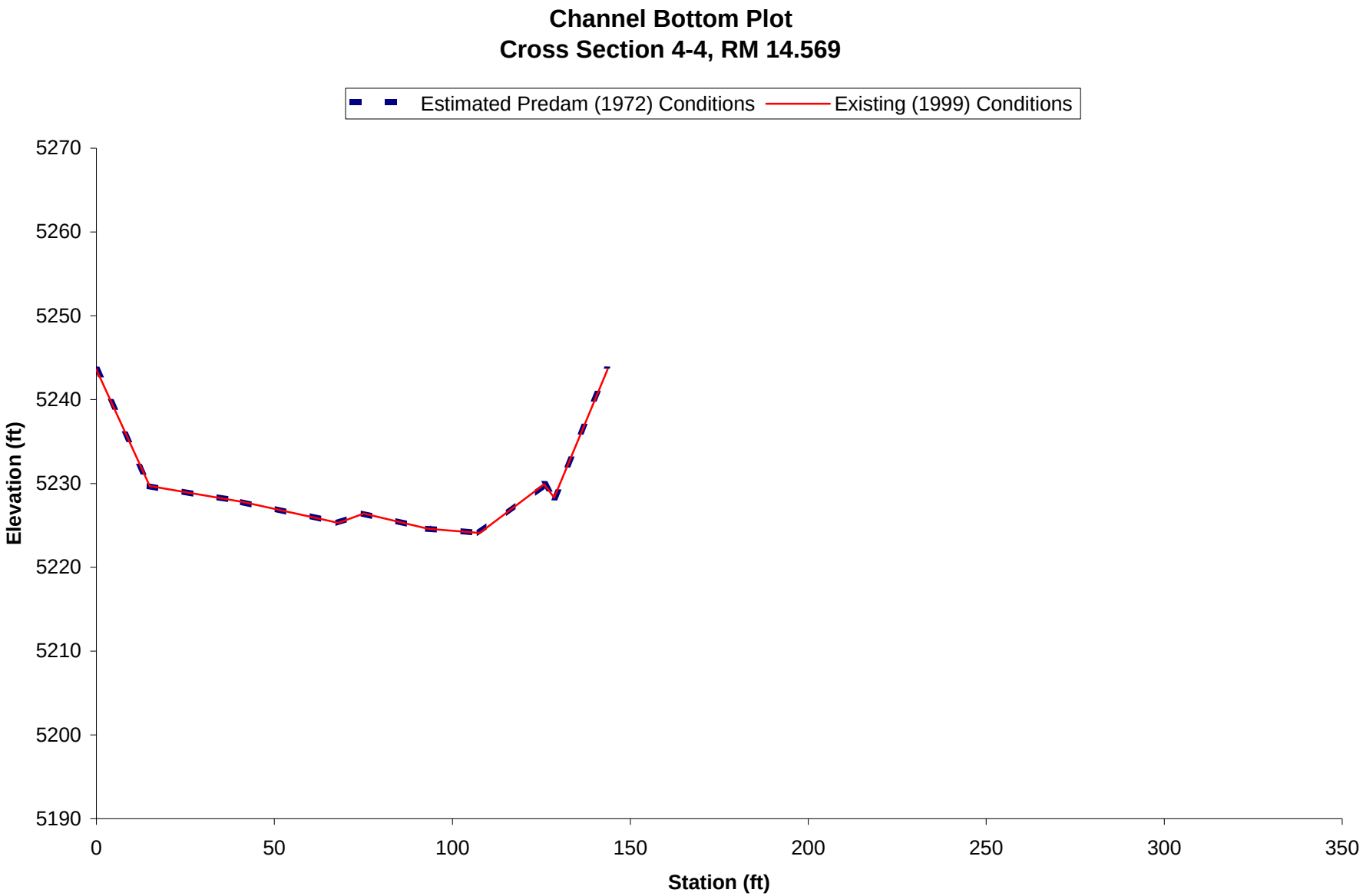
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-4, RM 14.569
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
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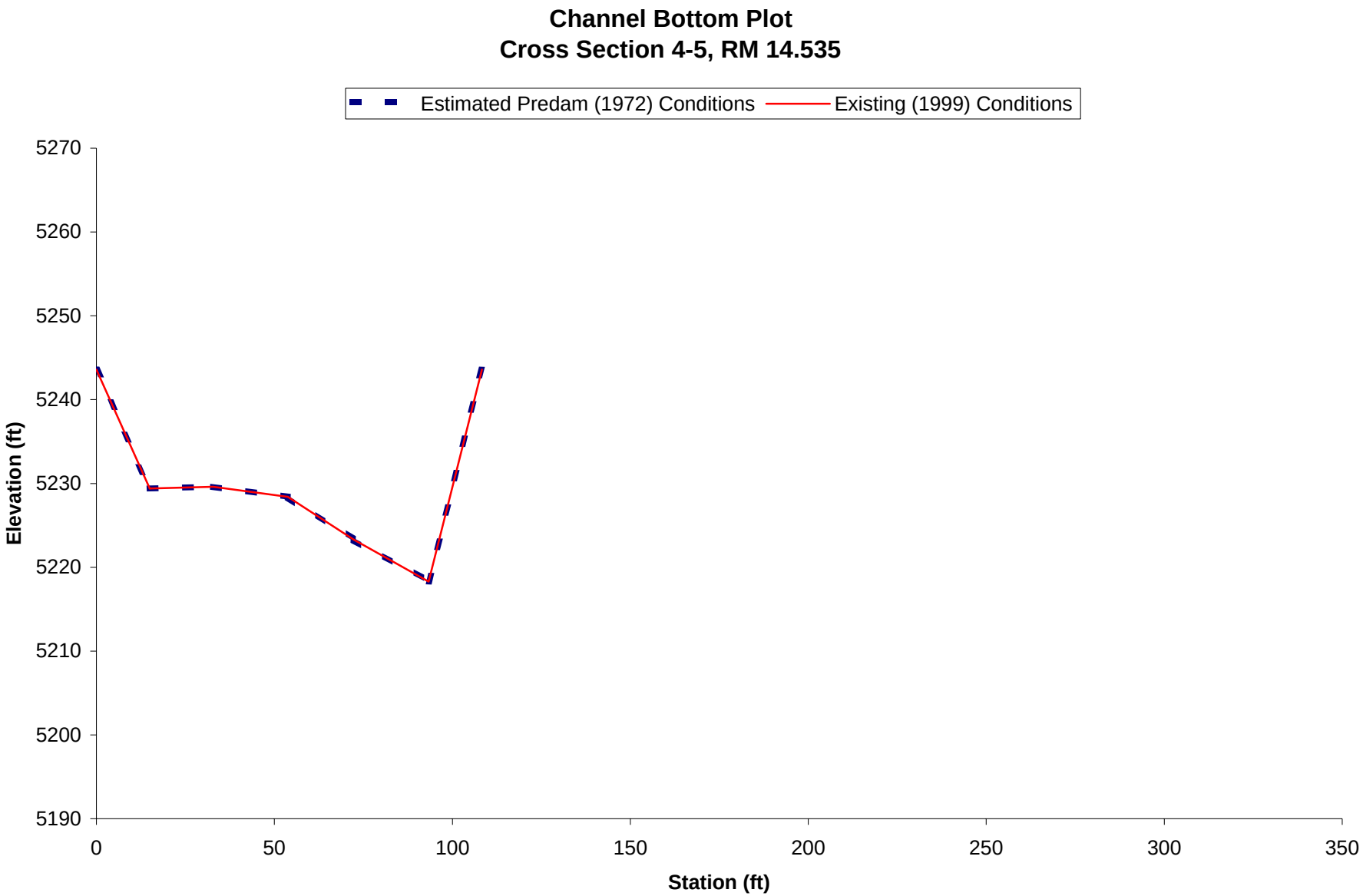
5230
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-5, RM 14.535
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
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5240
5230
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5210
5200
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200
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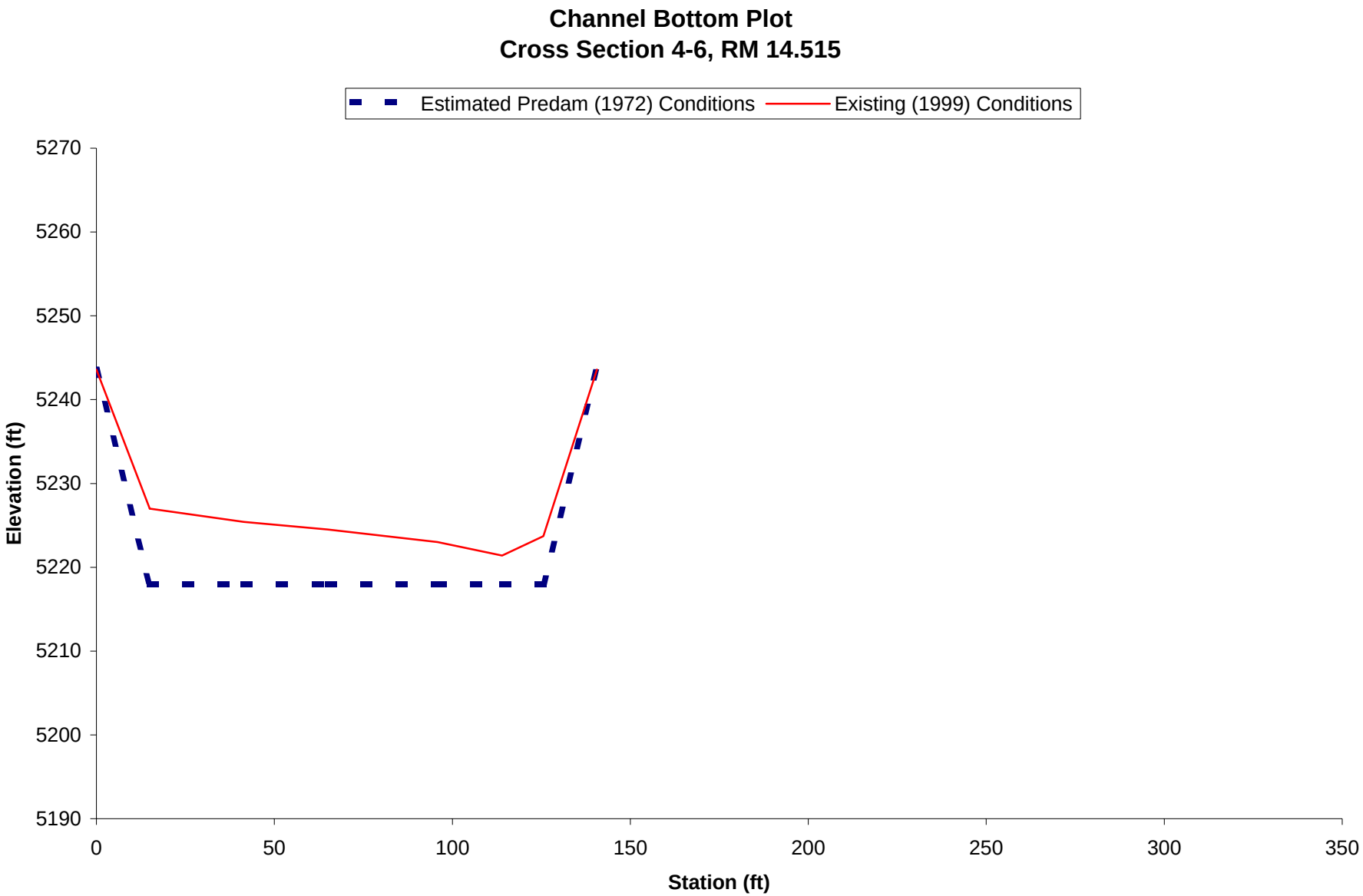
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-6, RM 14.515
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5210
5200
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100
150
200
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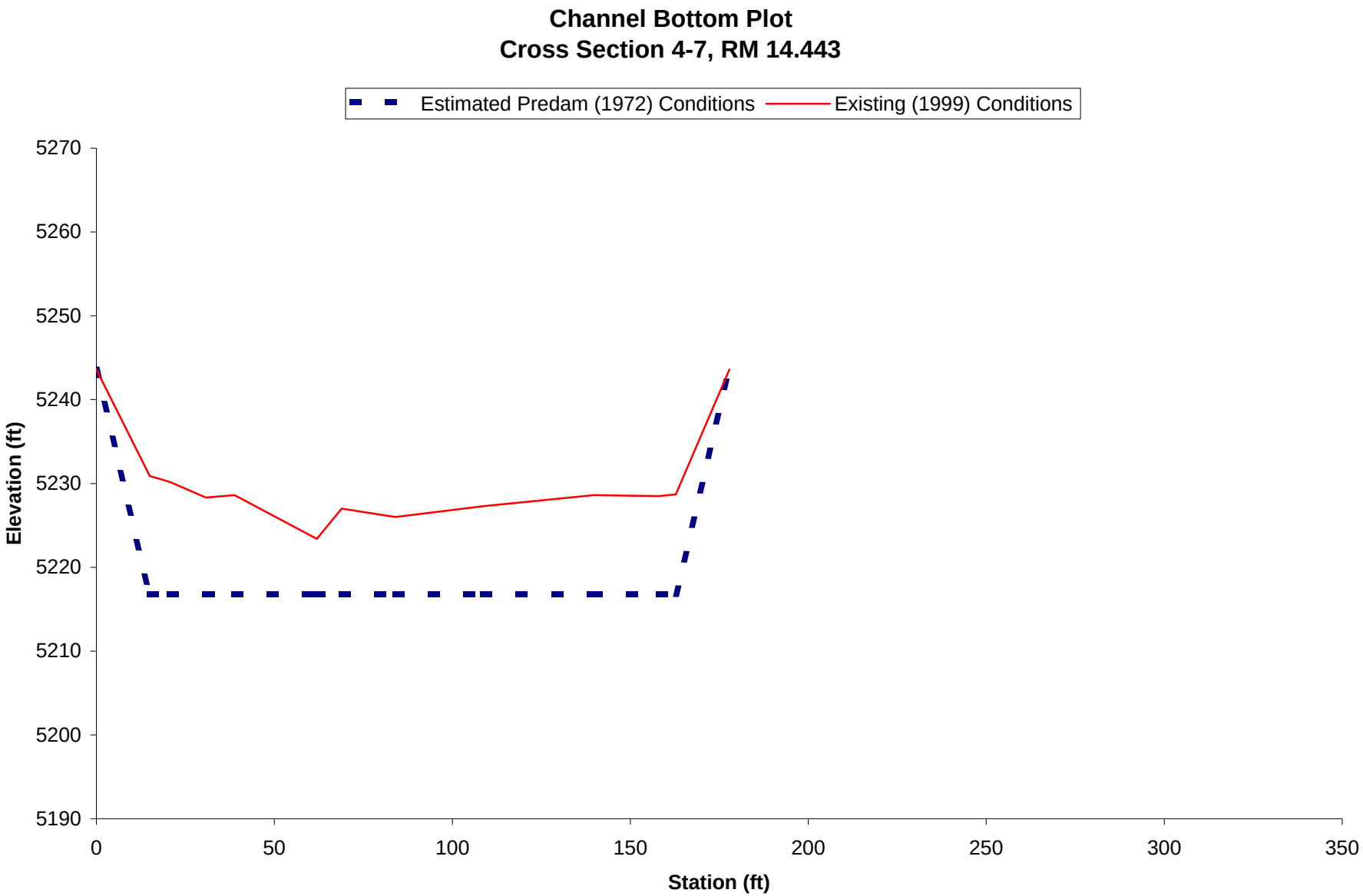
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-7, RM 14.443
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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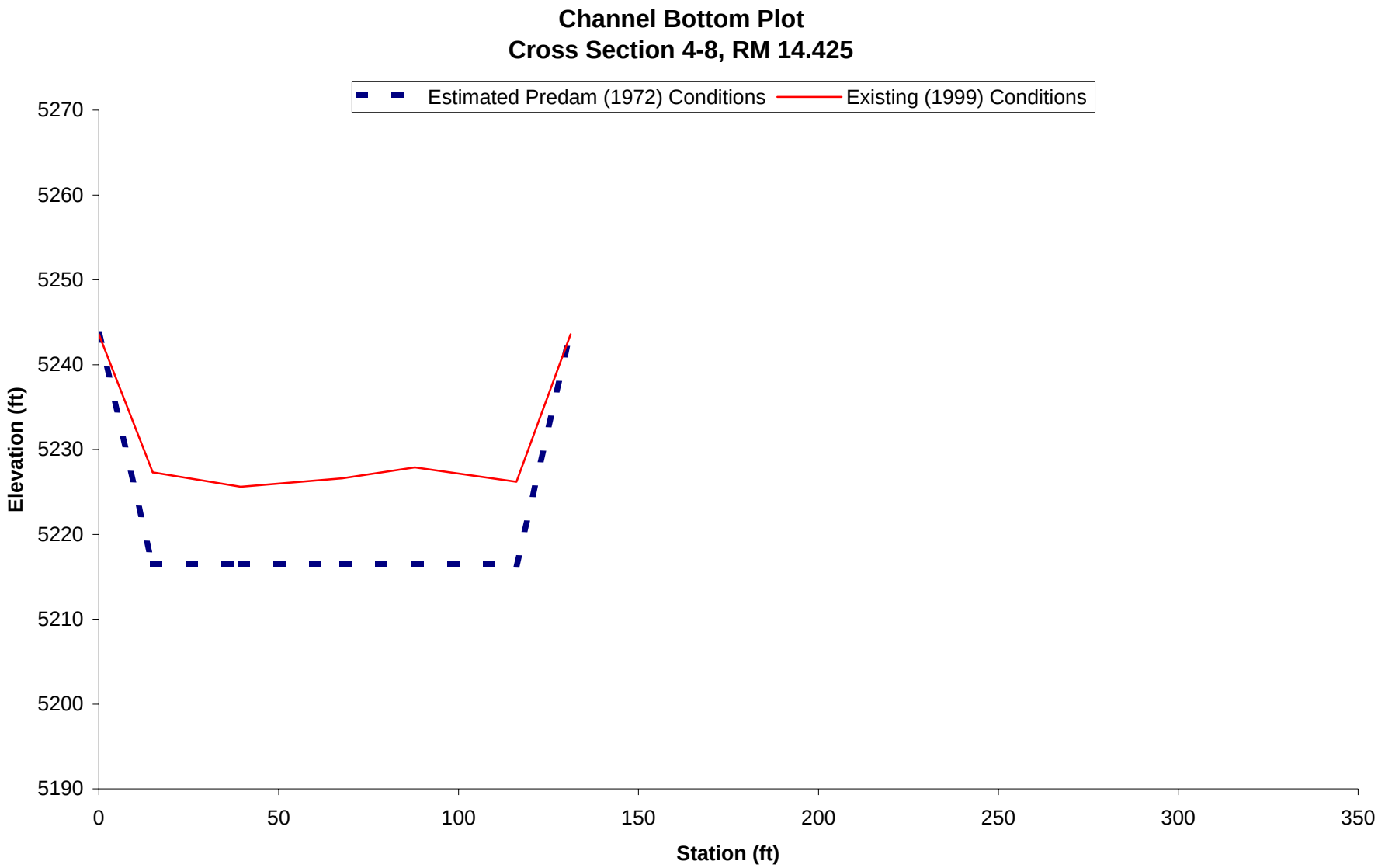
Station (ft)


Channel Bottom Plot
Cross Section 4-8, RM 14.425
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5210
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100
150
200
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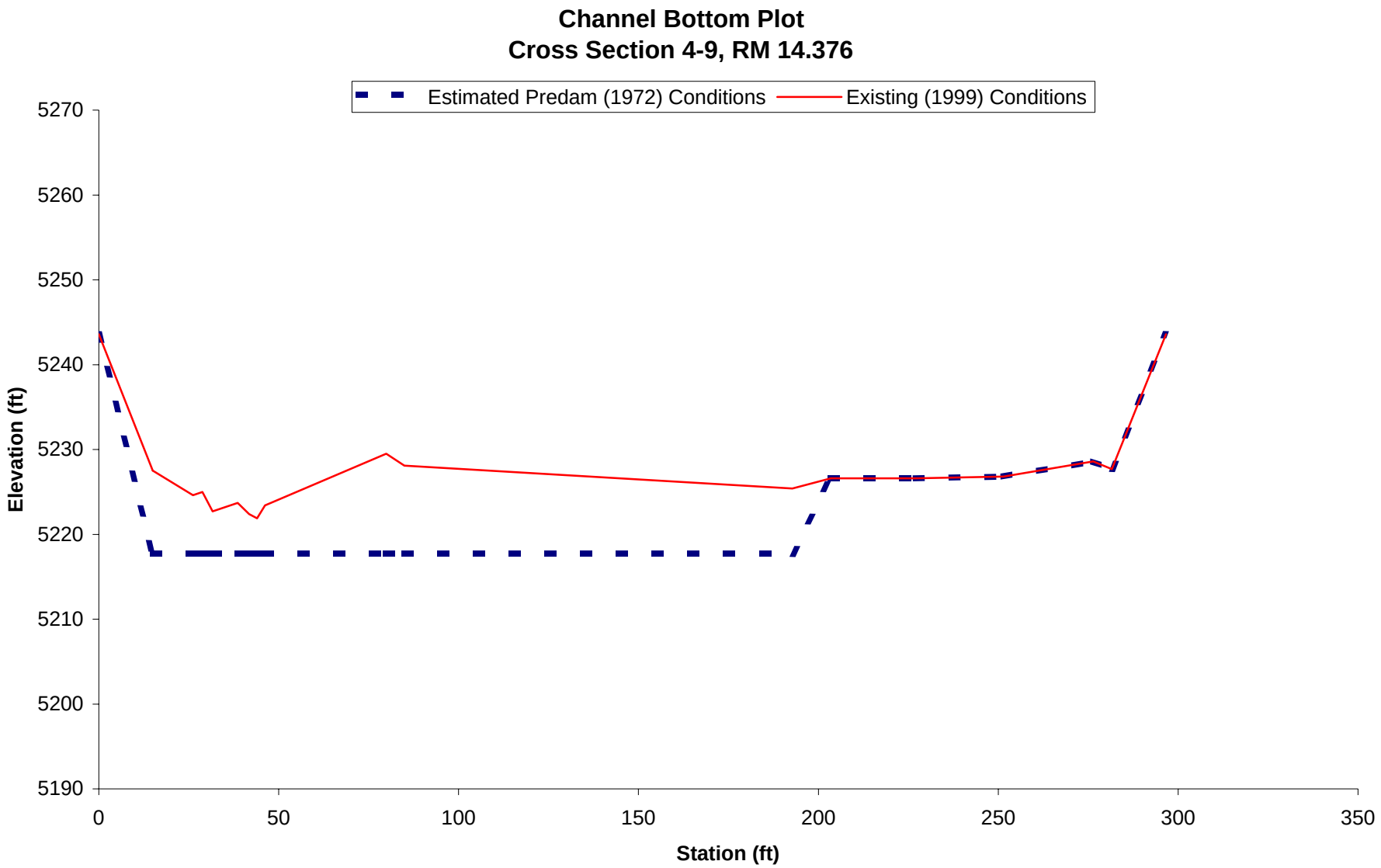
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-9, RM 14.376
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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100
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200
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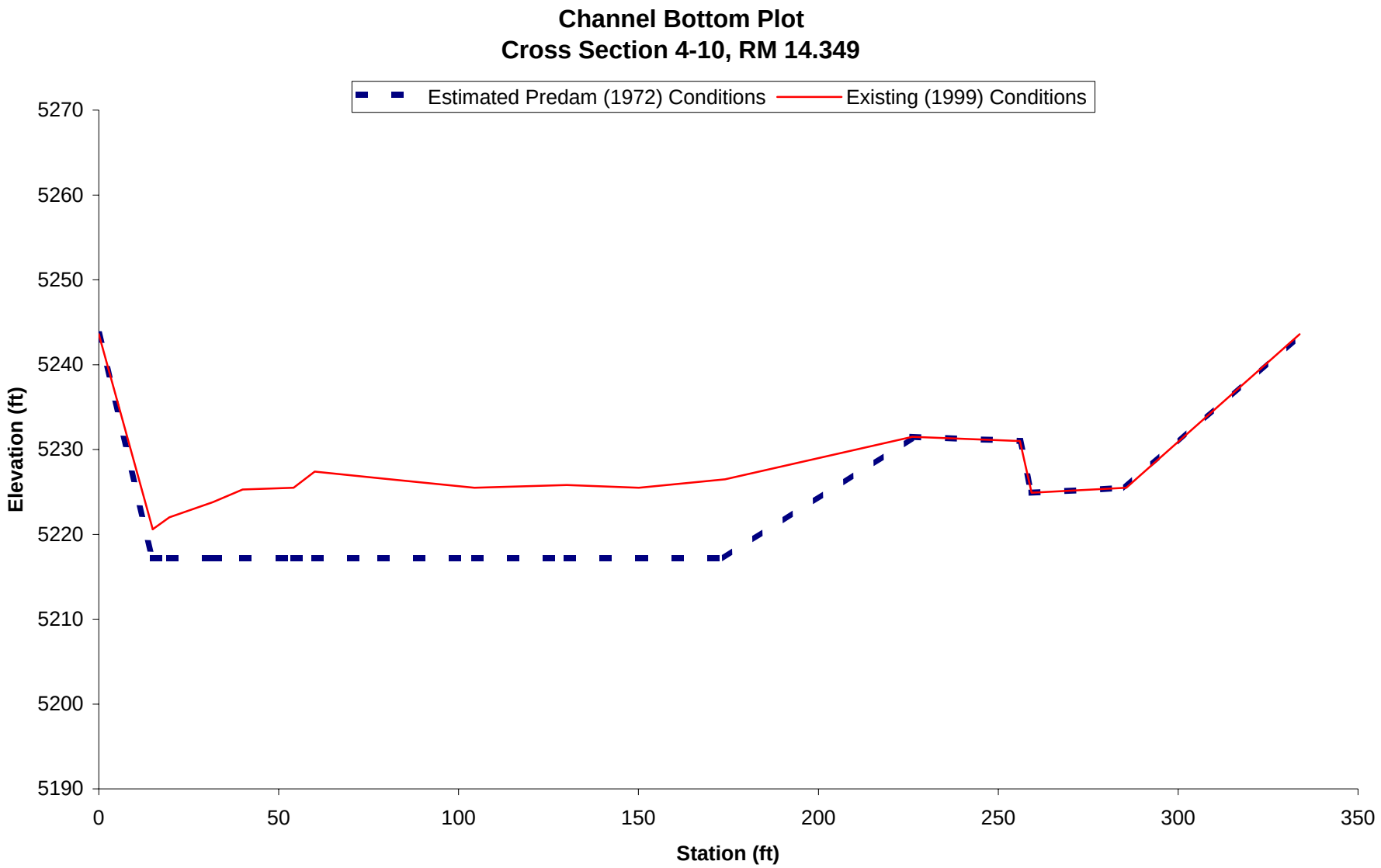
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-10, RM 14.349
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5230
5220
5210
5200
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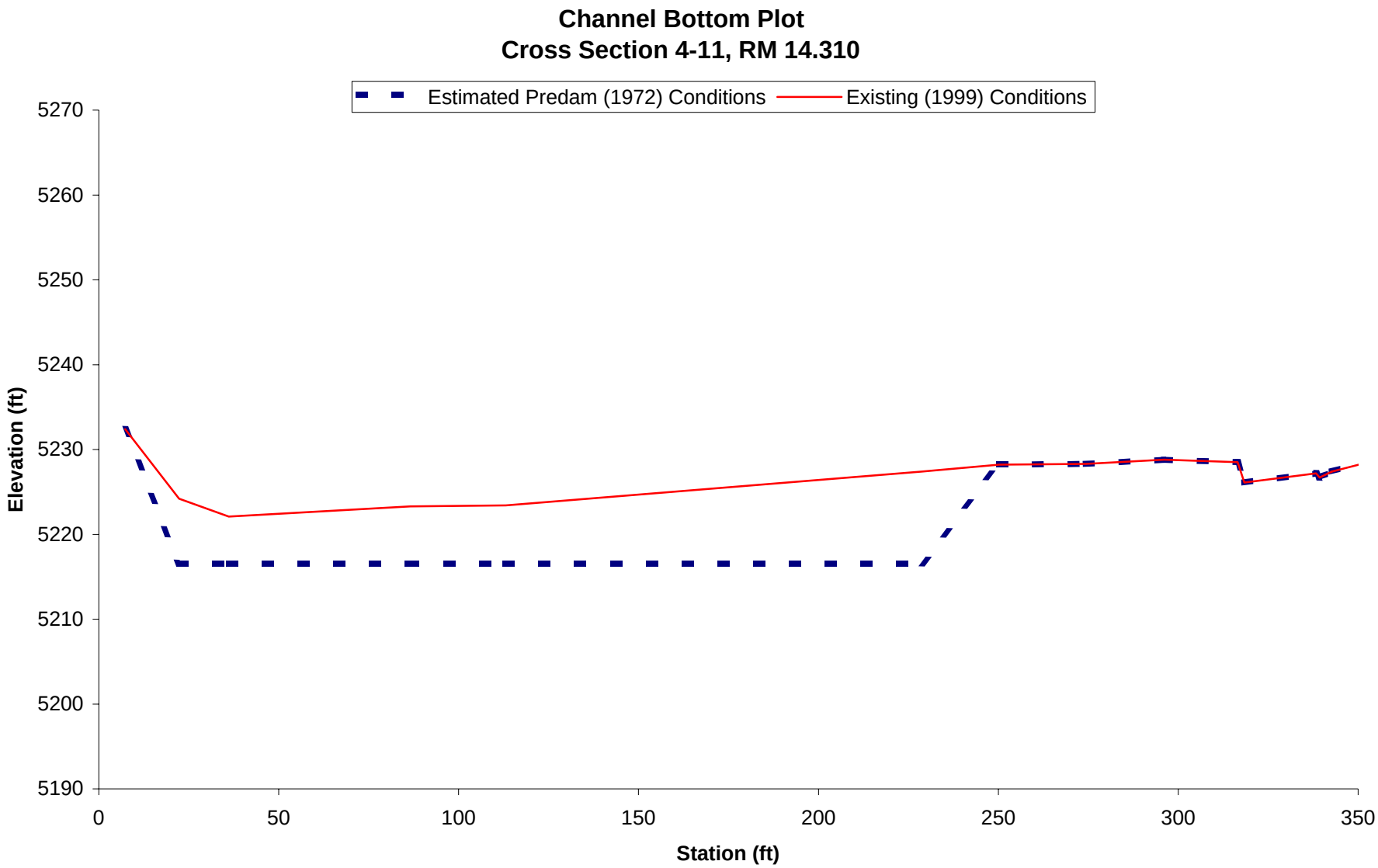
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-11, RM 14.310
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5220
5210
5200
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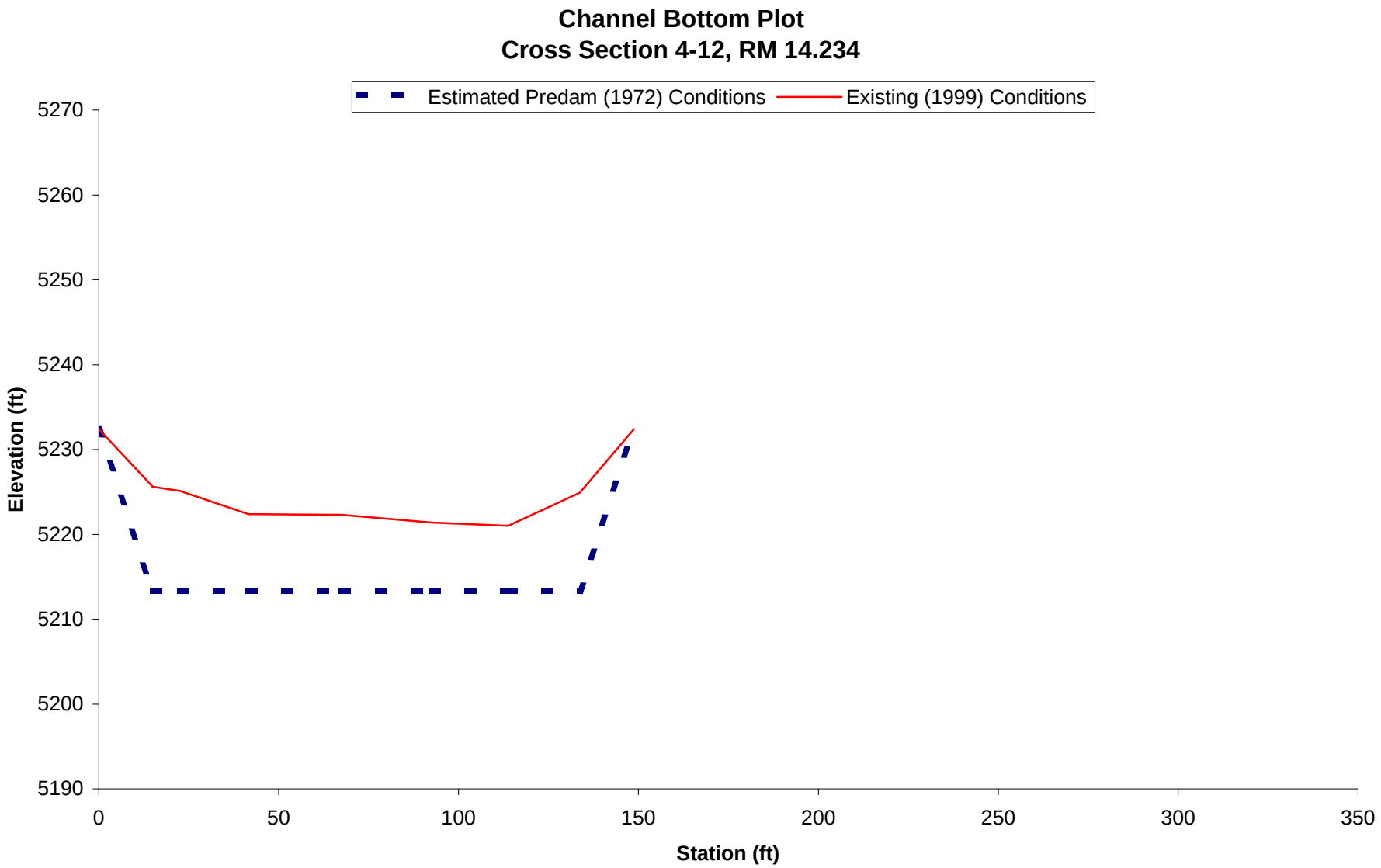
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-12, RM 14.234
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5210
5200
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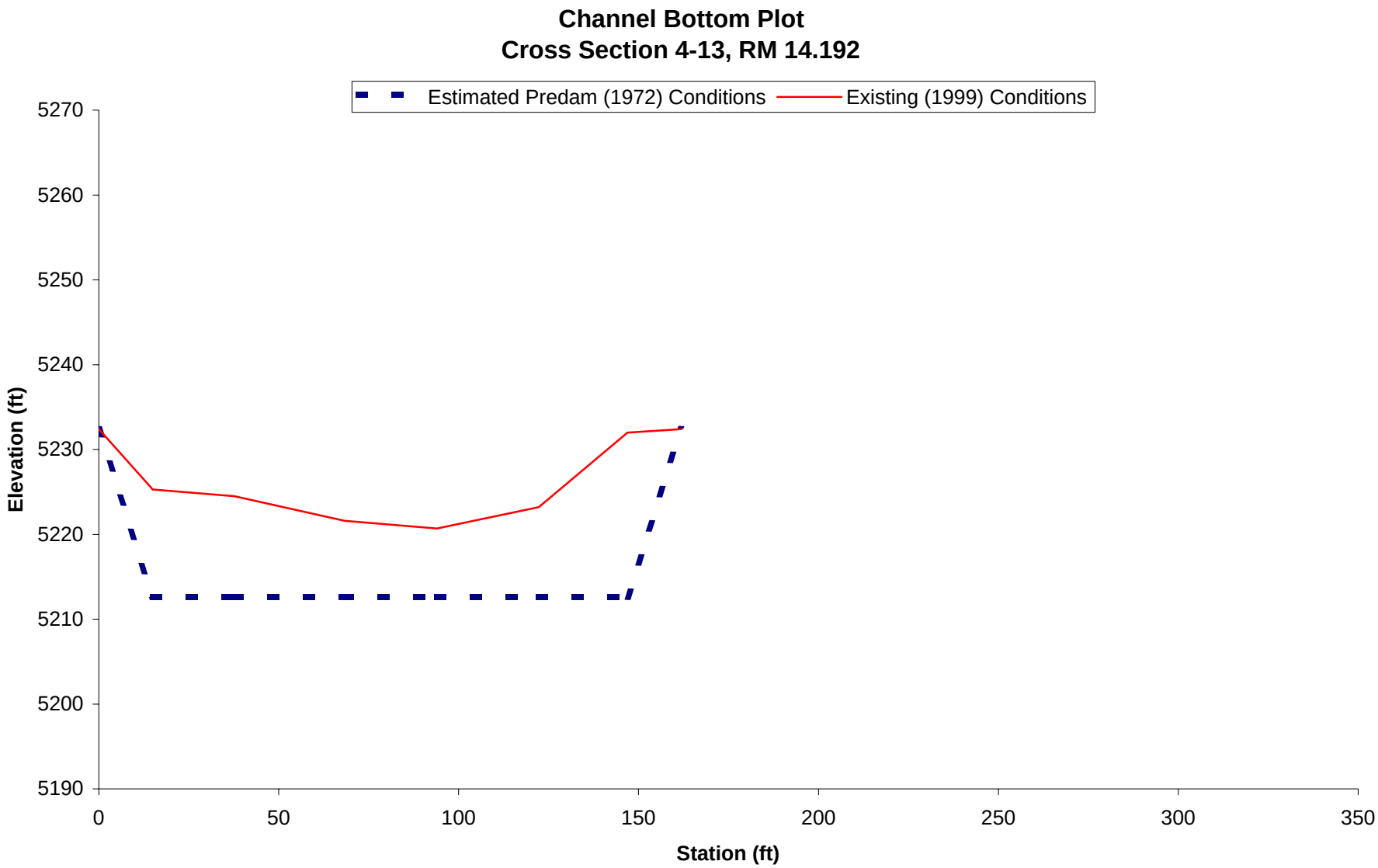
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-13, RM 14.192
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5220
5210
5200
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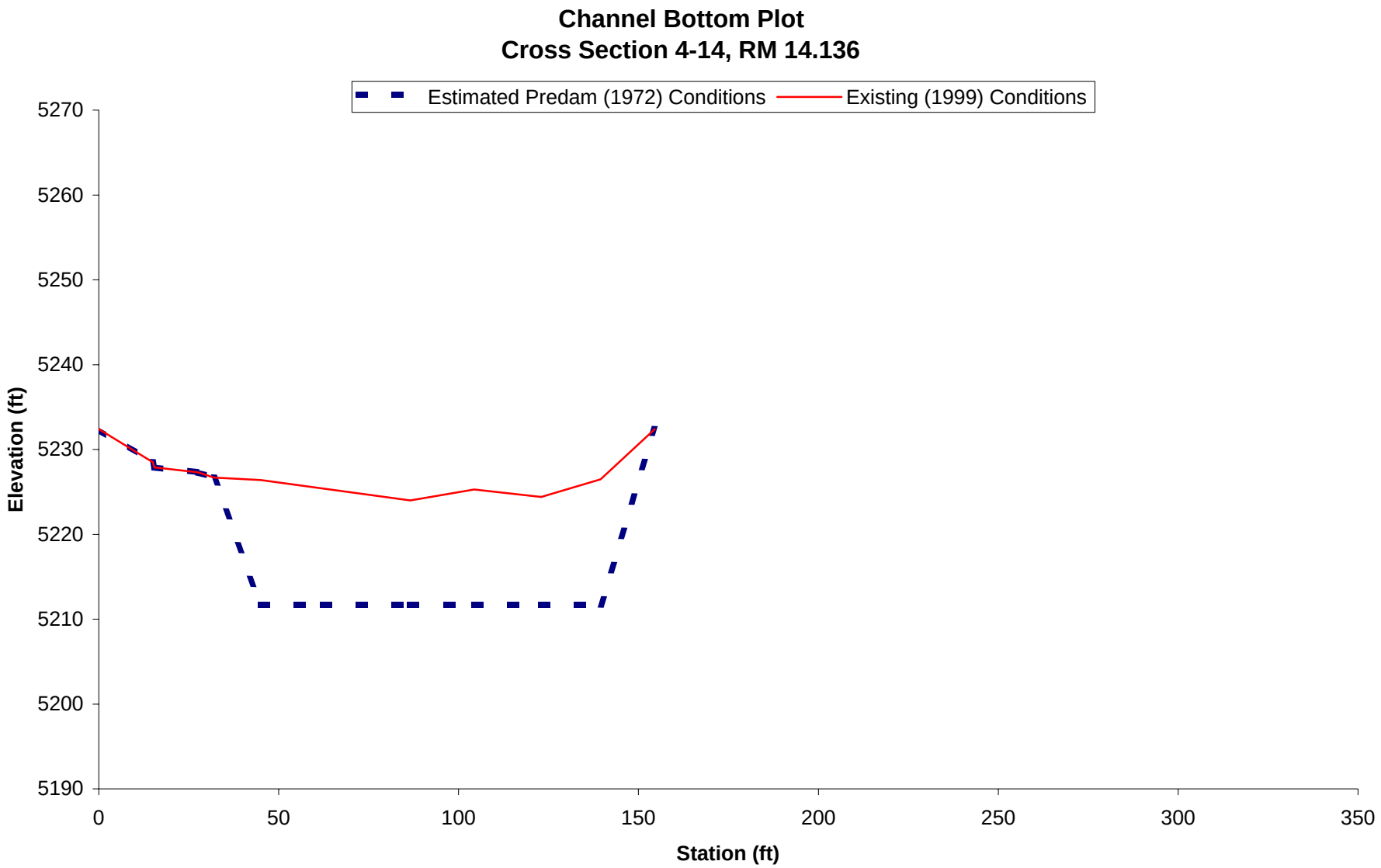
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-14, RM 14.136
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5220
5210
5200
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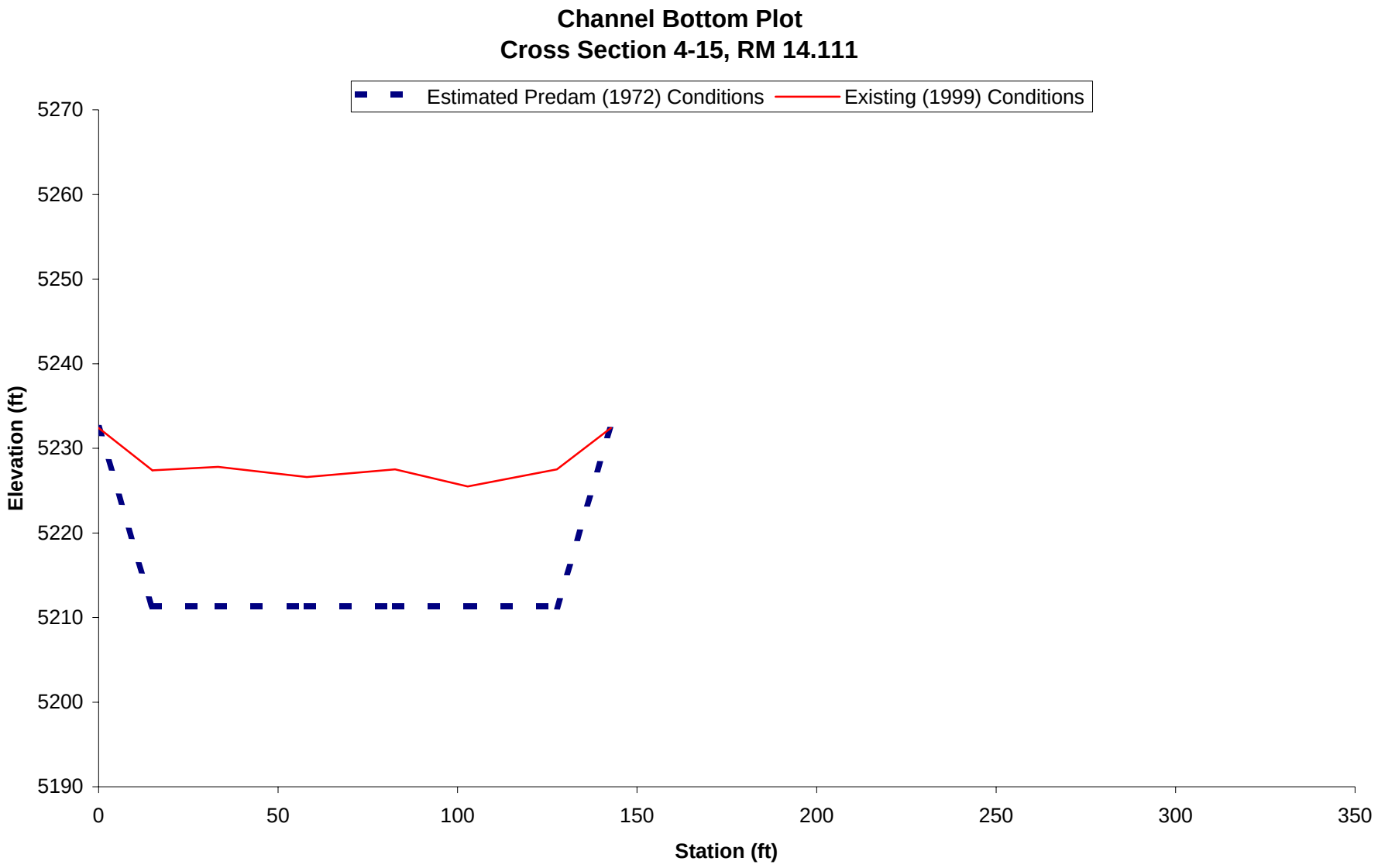
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 4-15, RM 14.111
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
5250
5240
5230
5220
5210
5200
5190
0
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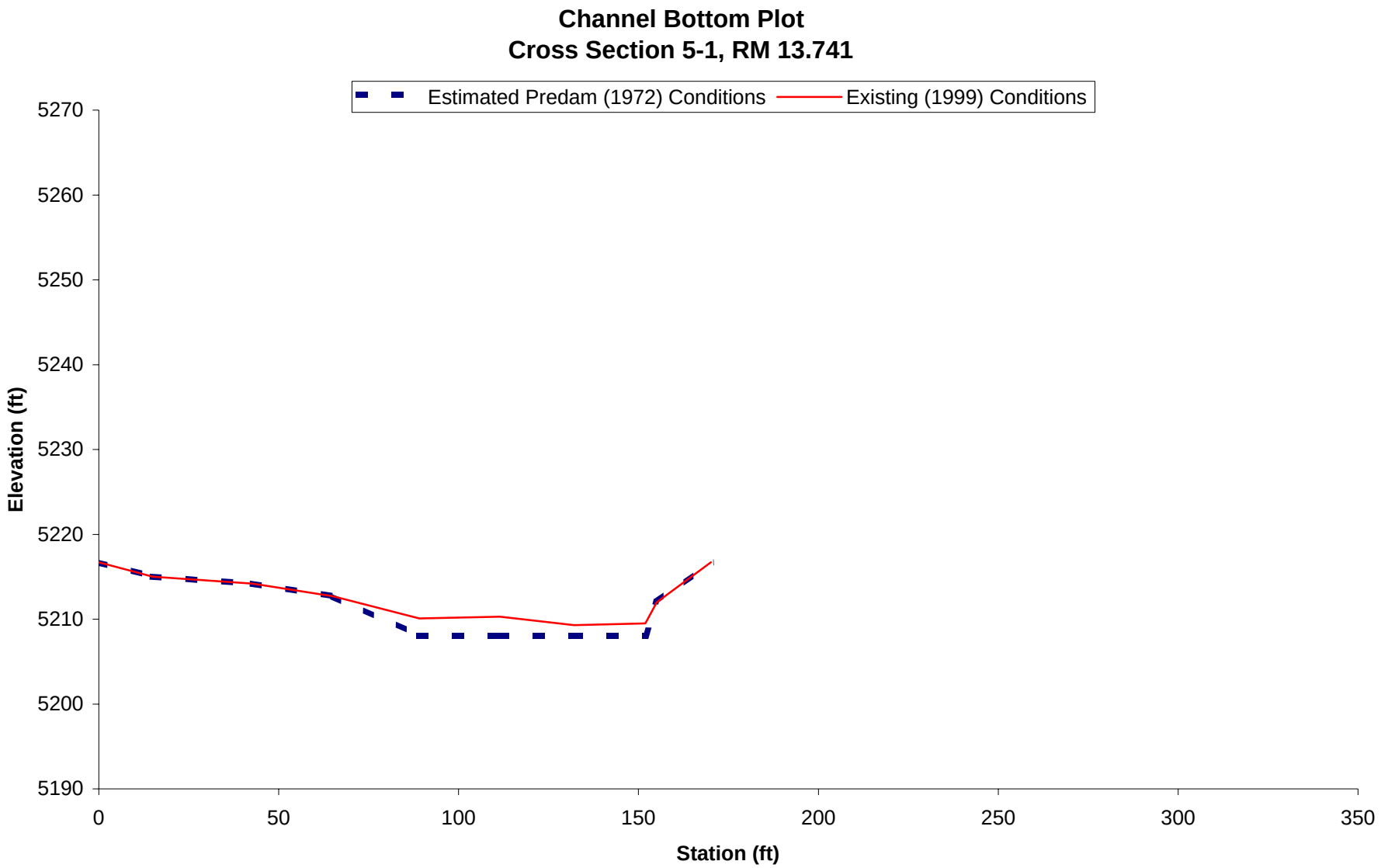
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-1, RM 13.741
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
5250
5240
5230
5220
5210
5200
5190
0
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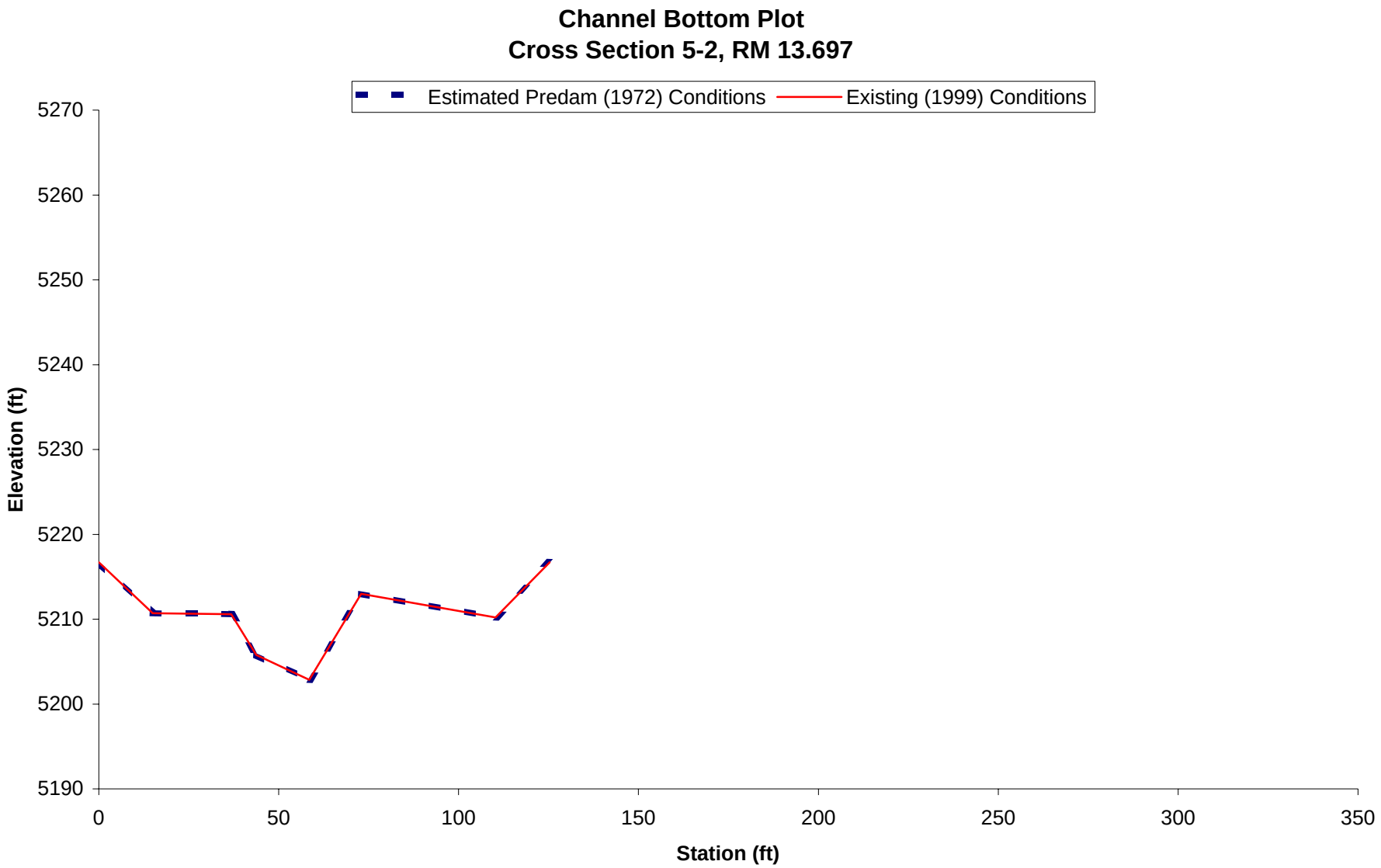
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-2, RM 13.697
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5250
5240
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5220
5210
5200
5190
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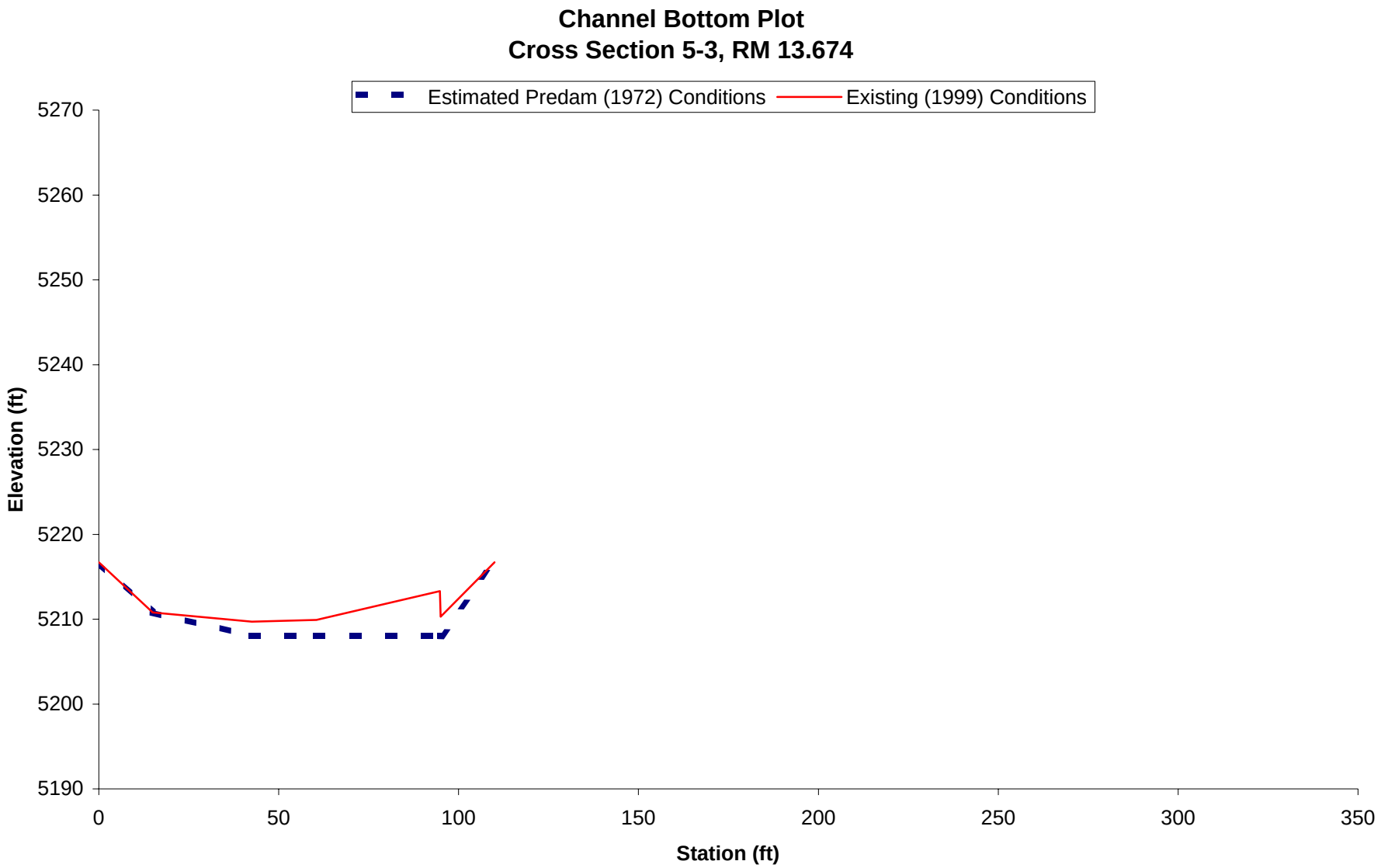
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-3, RM 13.674
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5220
5210
5200
5190
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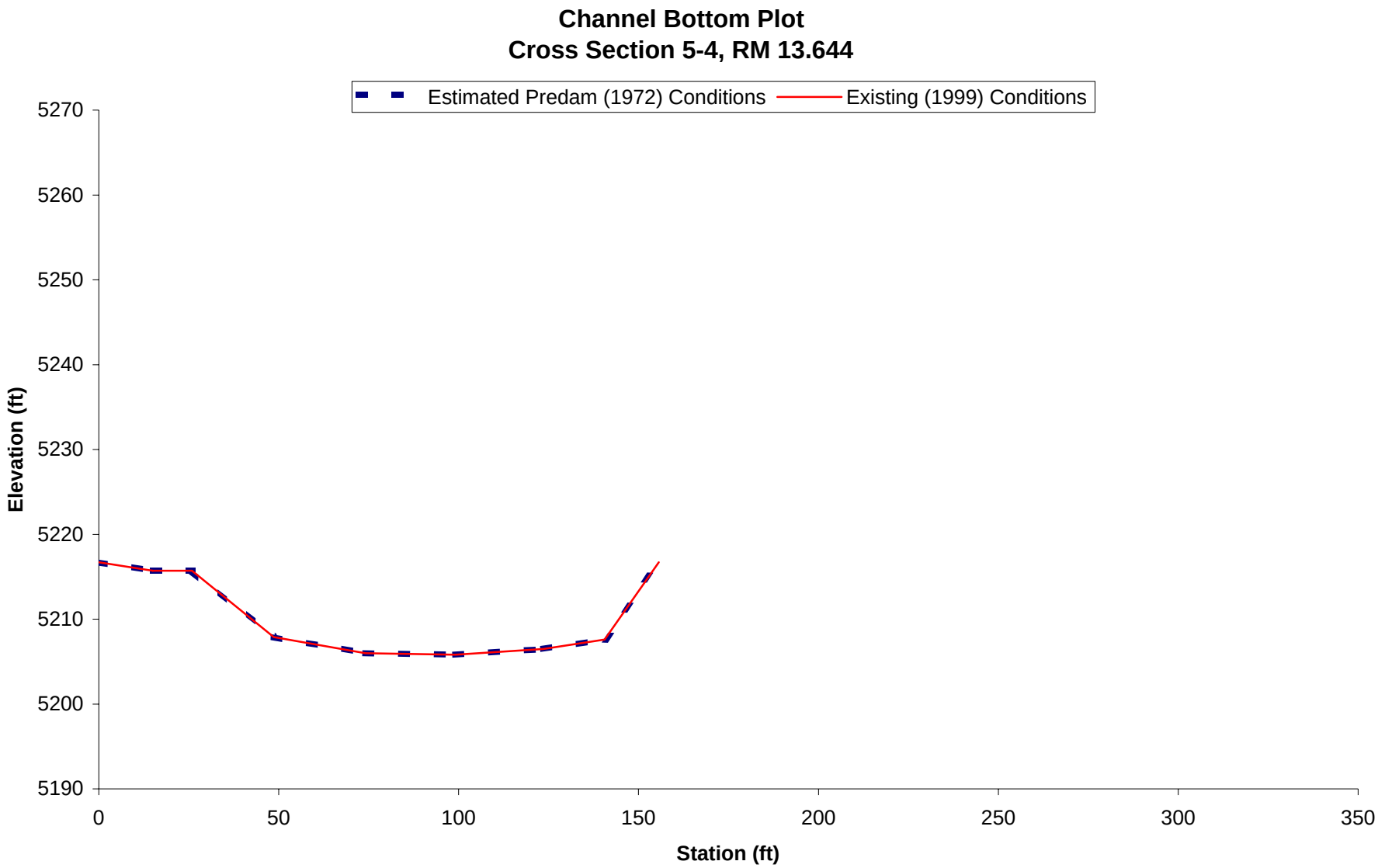
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-4, RM 13.644
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5250
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5220
5210
5200
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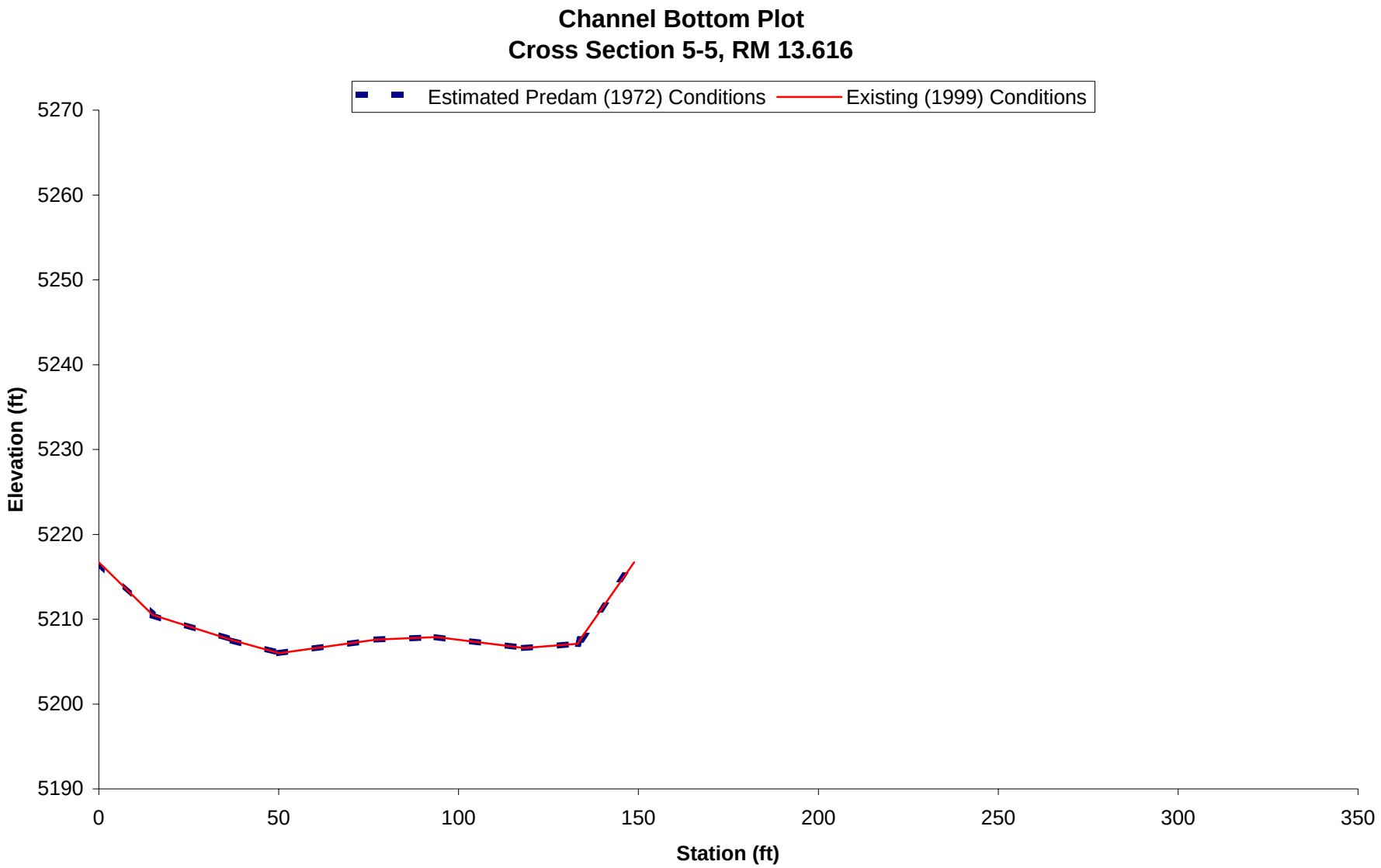
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-5, RM 13.616
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
5250
5240
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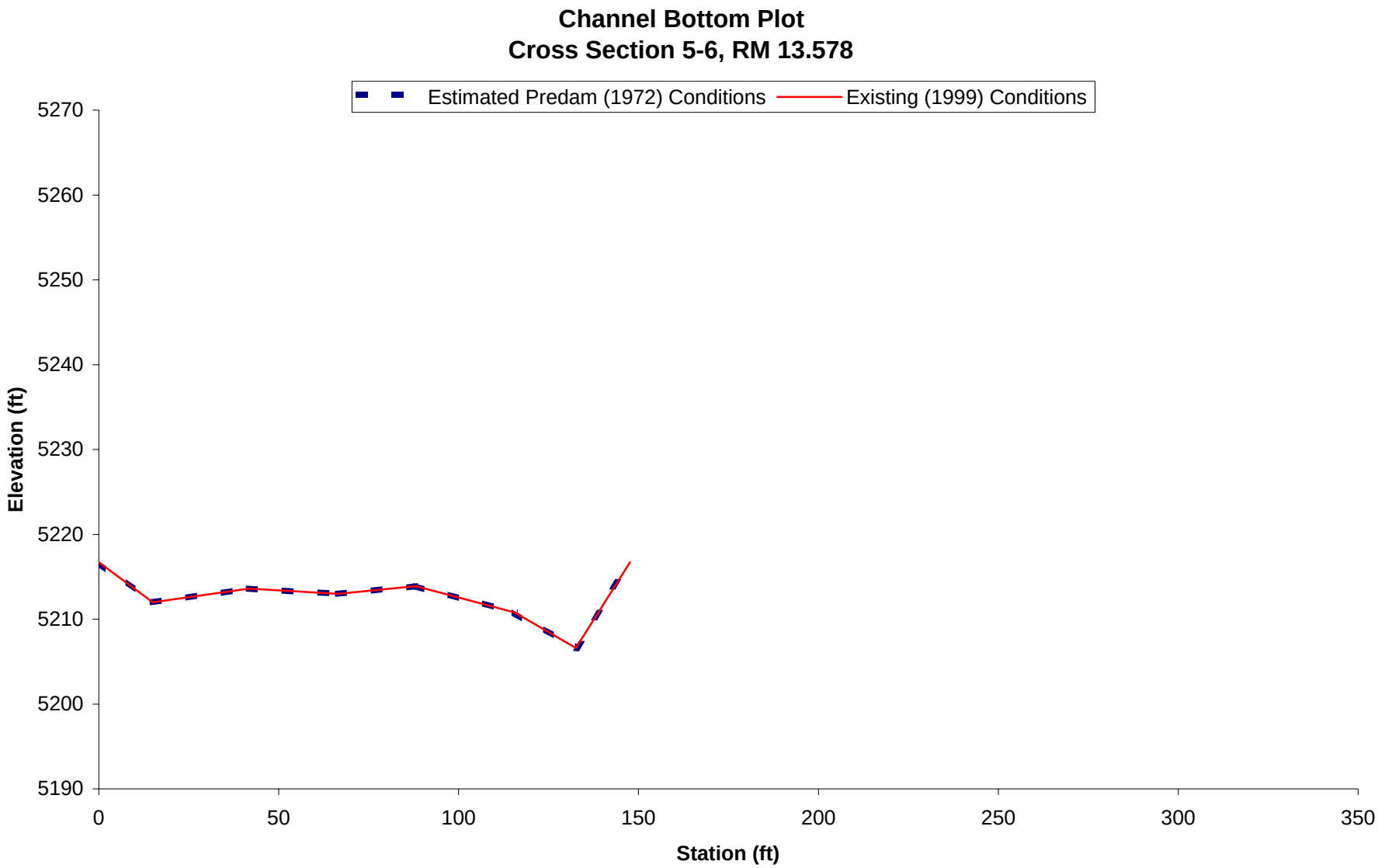
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-6, RM 13.578
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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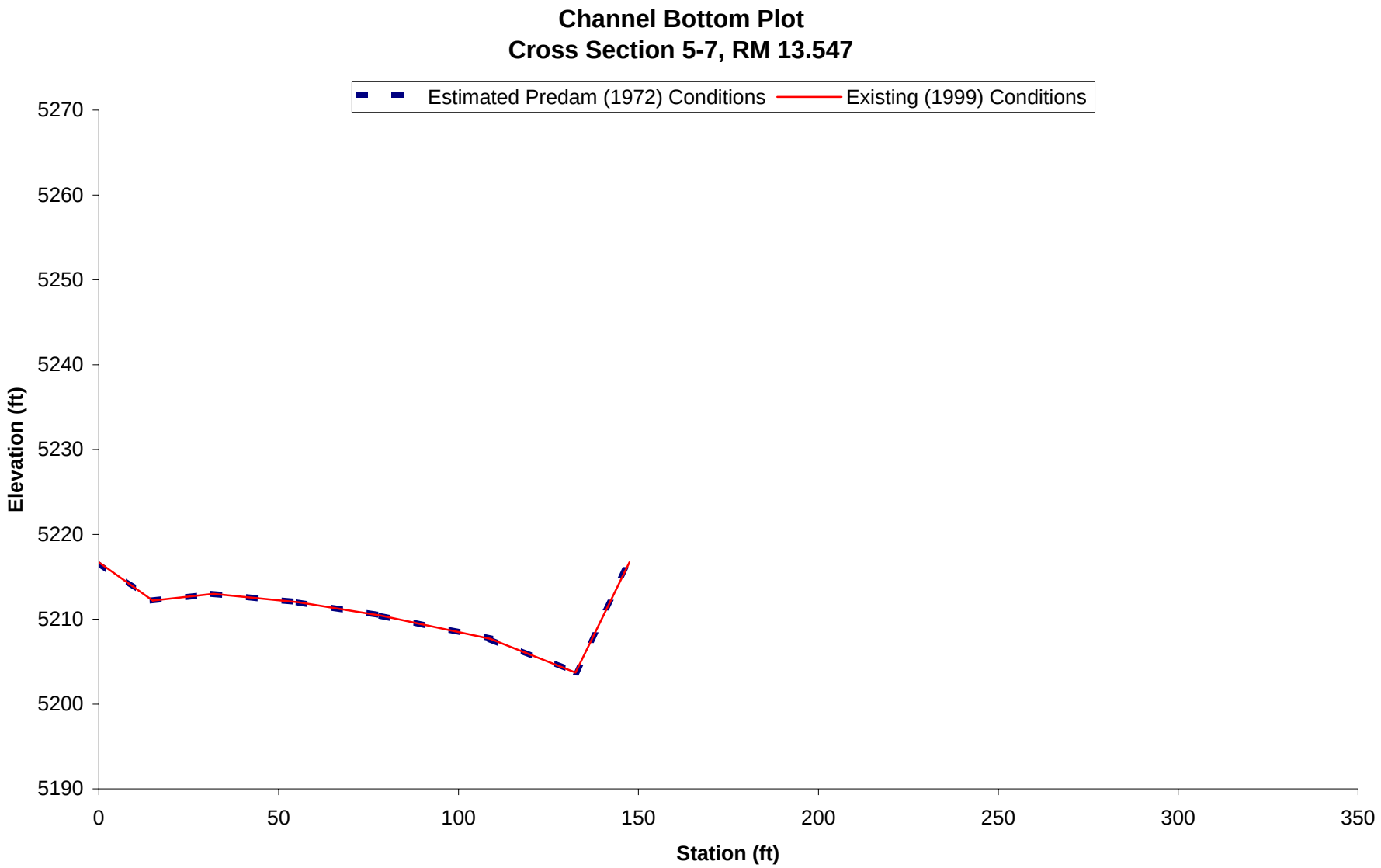
5250
5240
5230
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-7, RM 13.547
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
5260
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5240
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5220
5210
5200
5190
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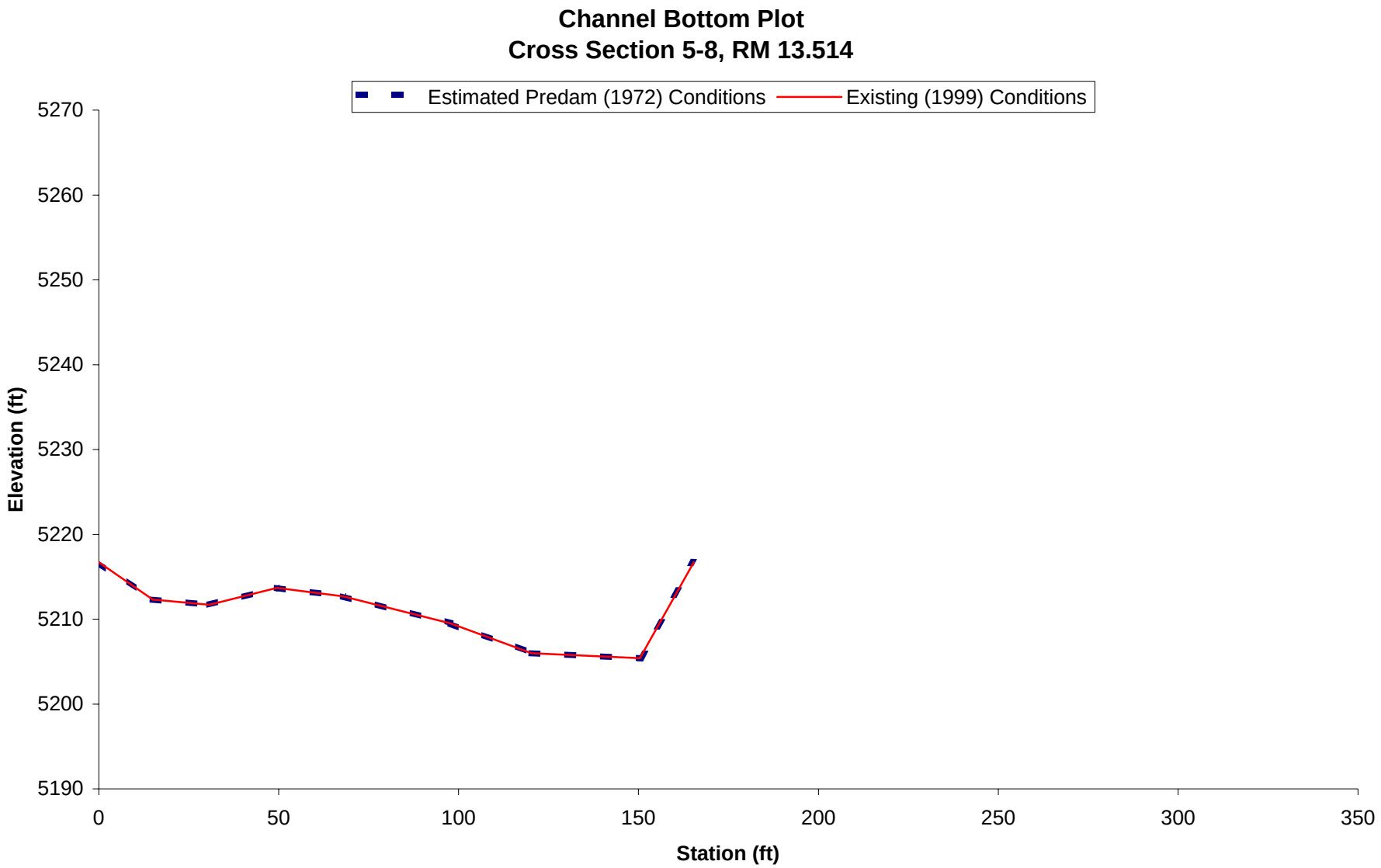
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-8, RM 13.514
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5220
5210
5200
5190
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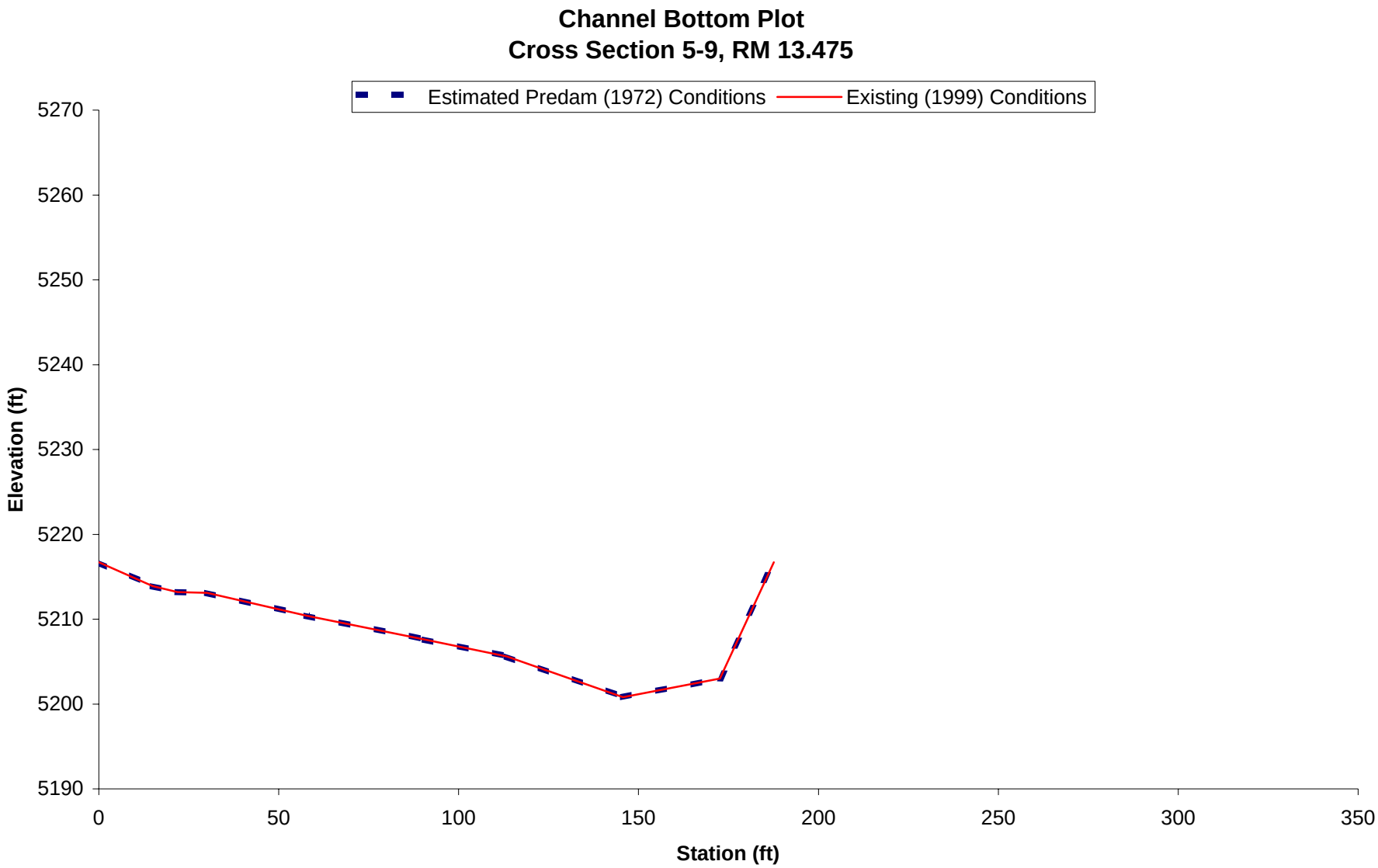
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-9, RM 13.475
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5220
5210
5200
5190
0
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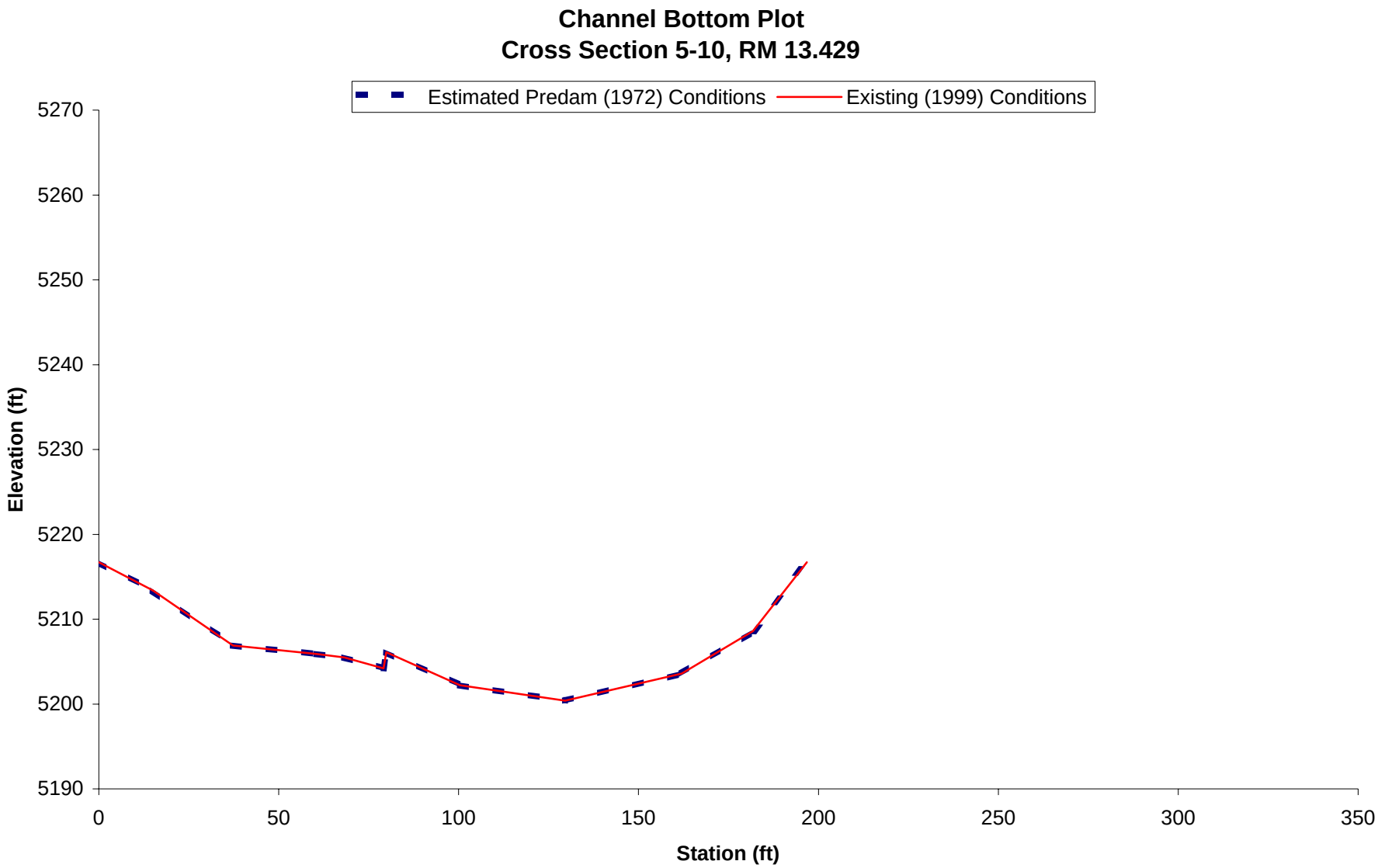
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-10, RM 13.429
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5230
5220
5210
5200
5190
0
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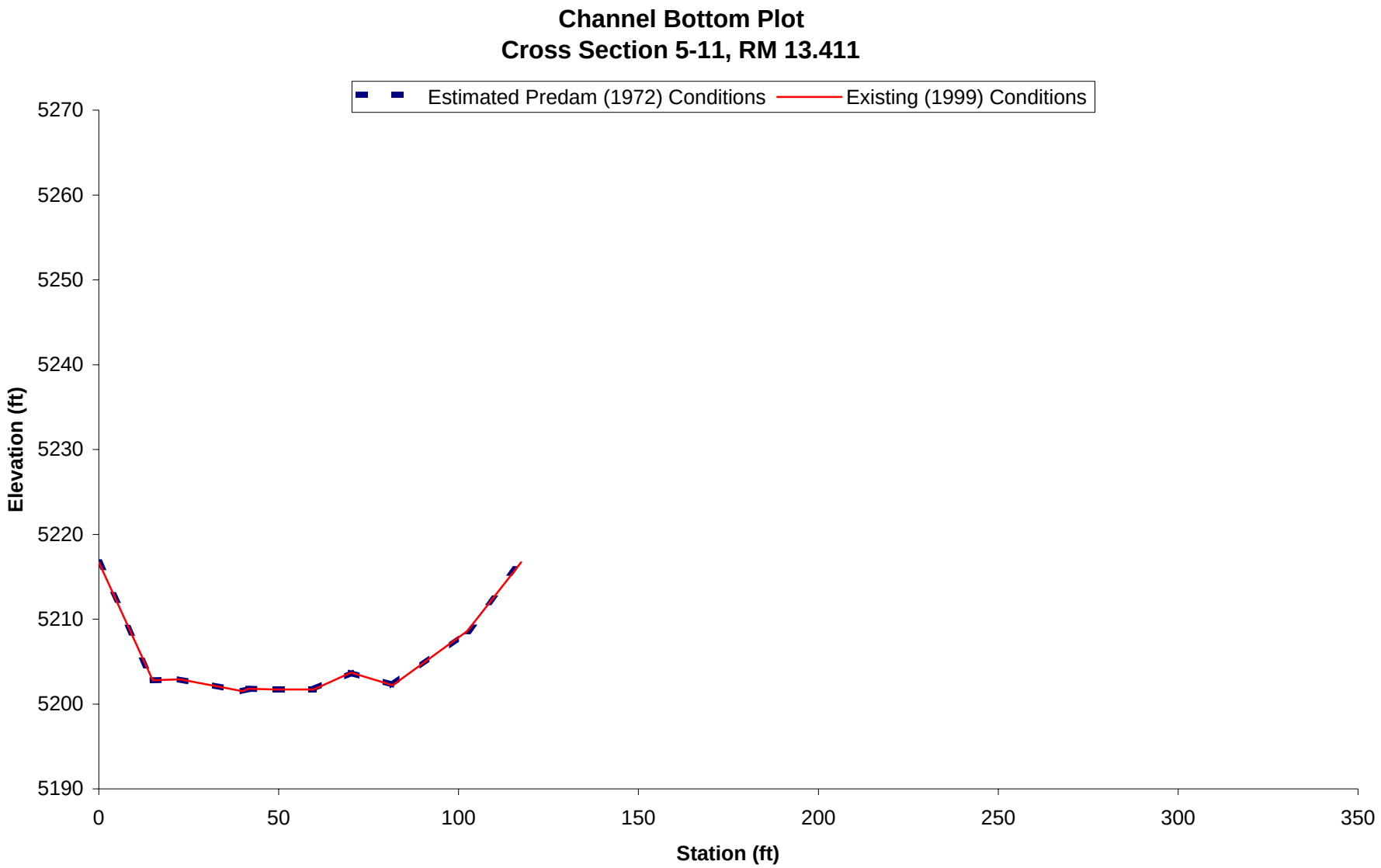
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-11, RM 13.411
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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5240
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5220
5210
5200
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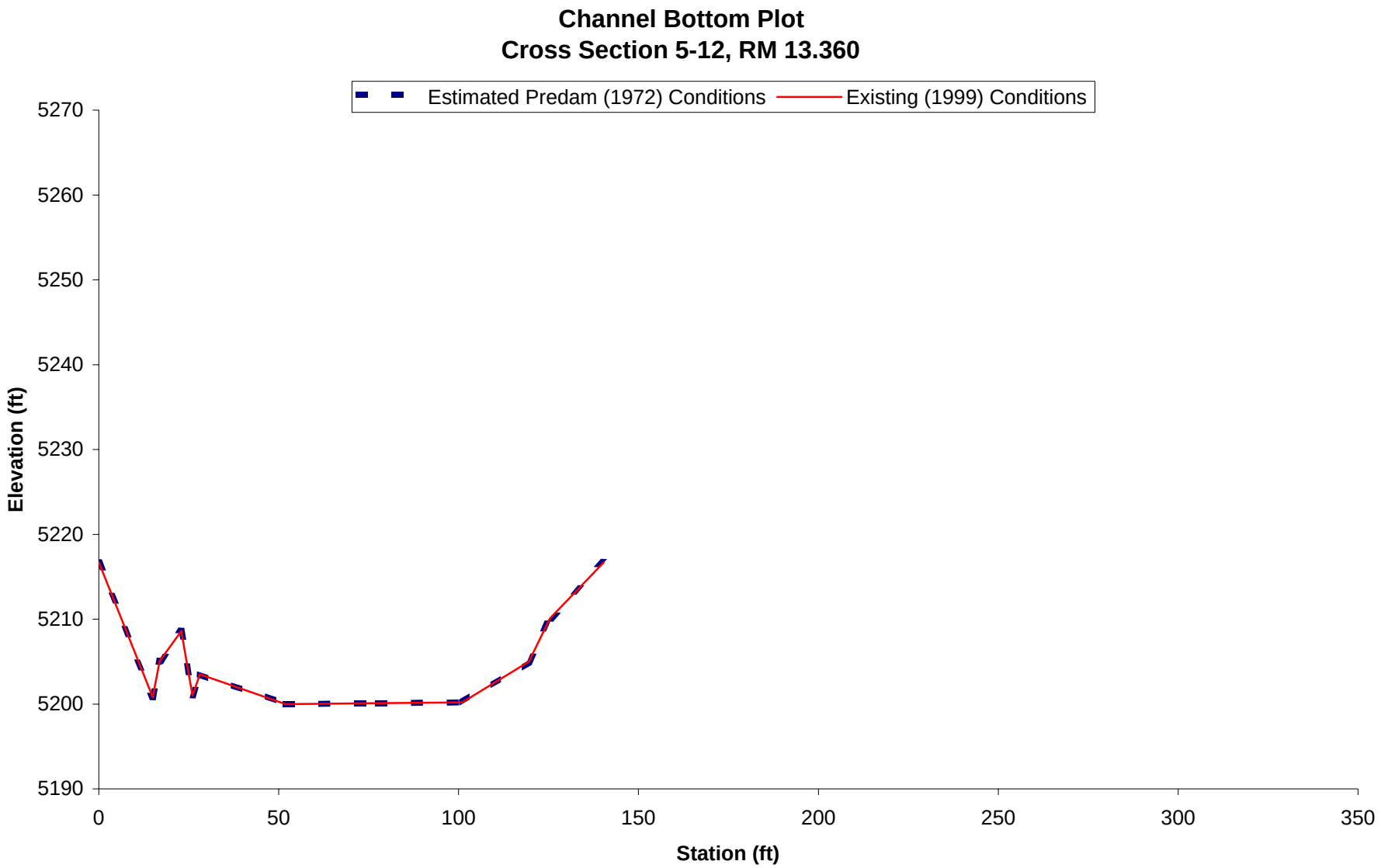
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-12, RM 13.360
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5210
5200
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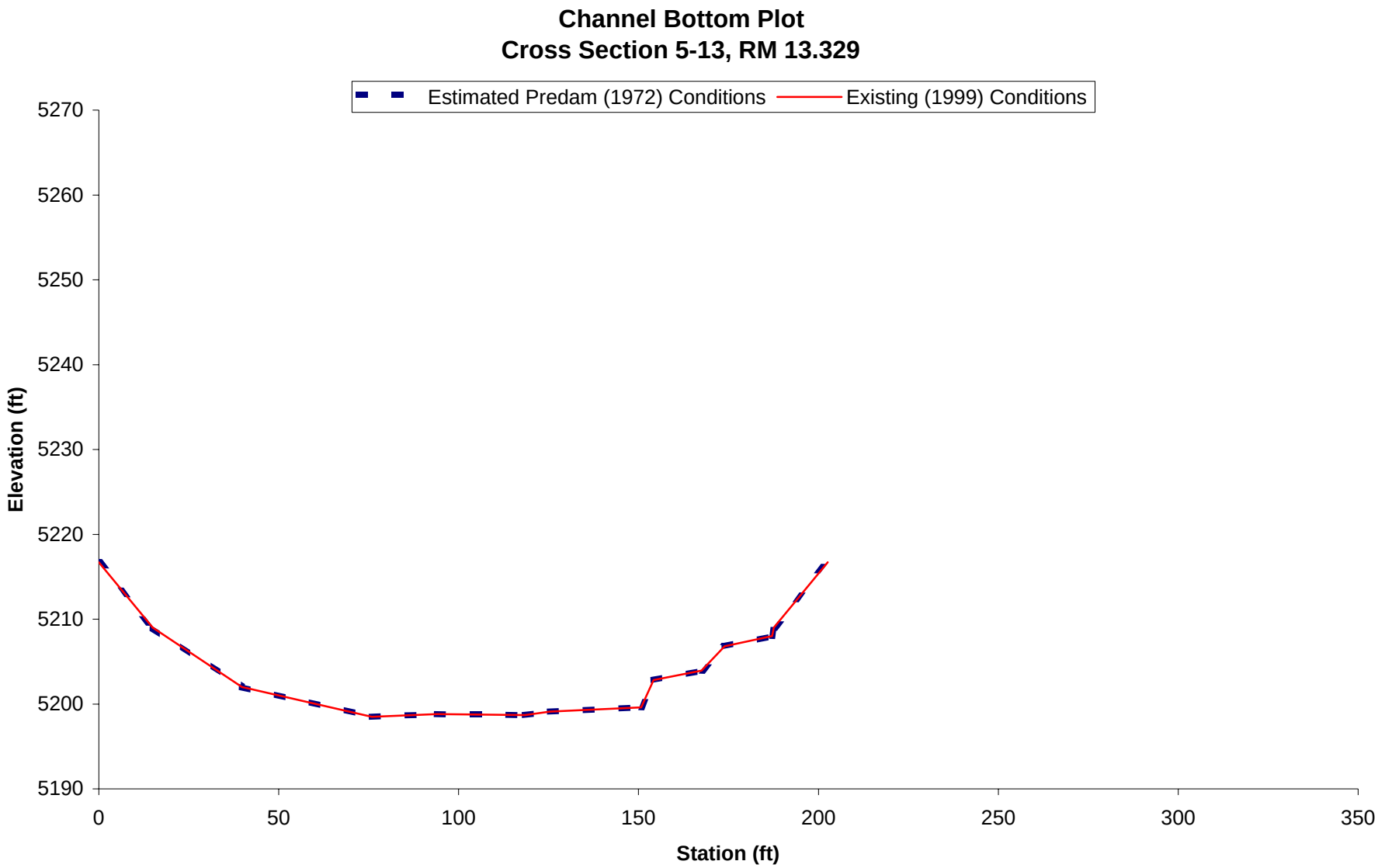
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-13, RM 13.329
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
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5210
5200
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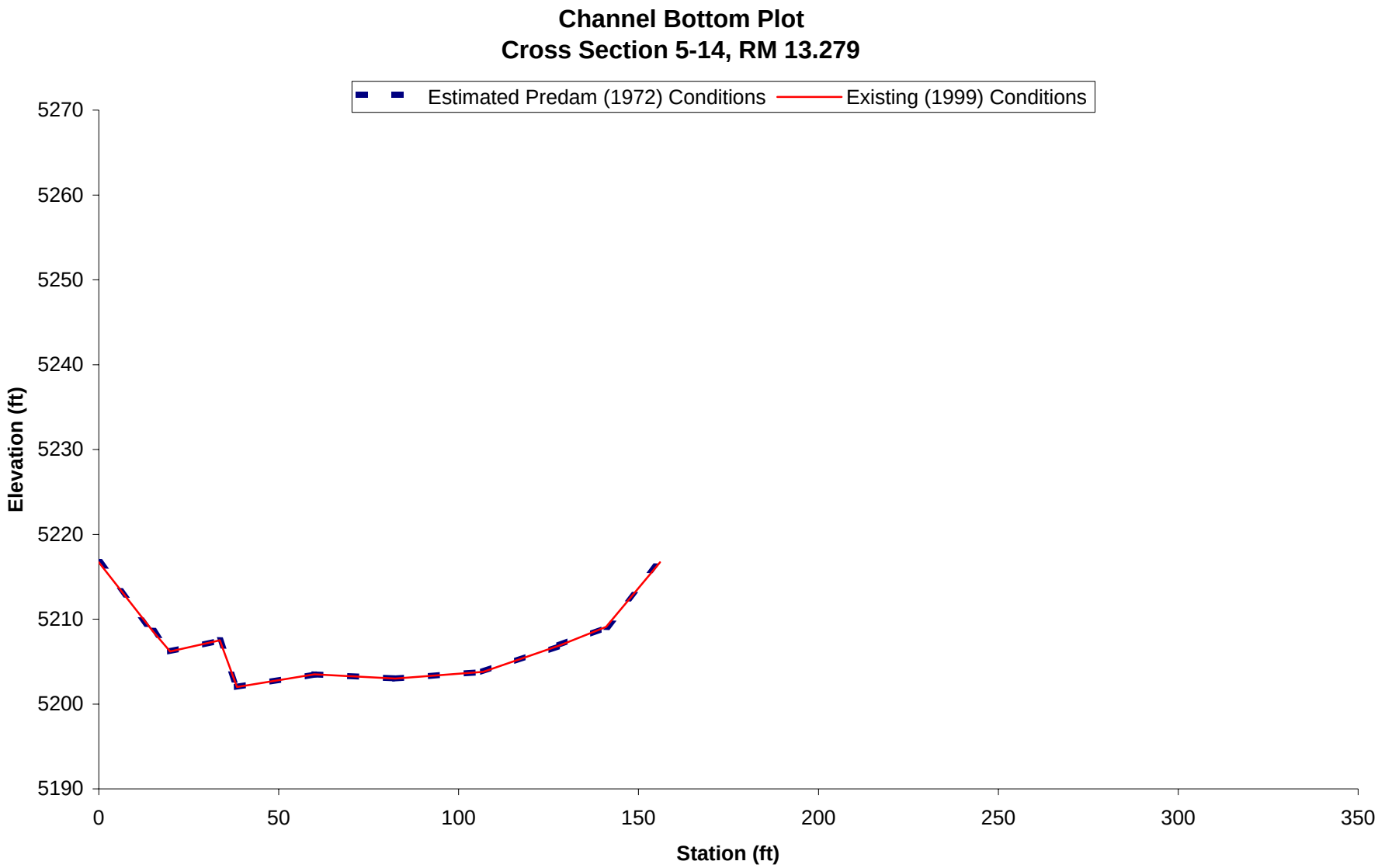
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 5-14, RM 13.279
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5270
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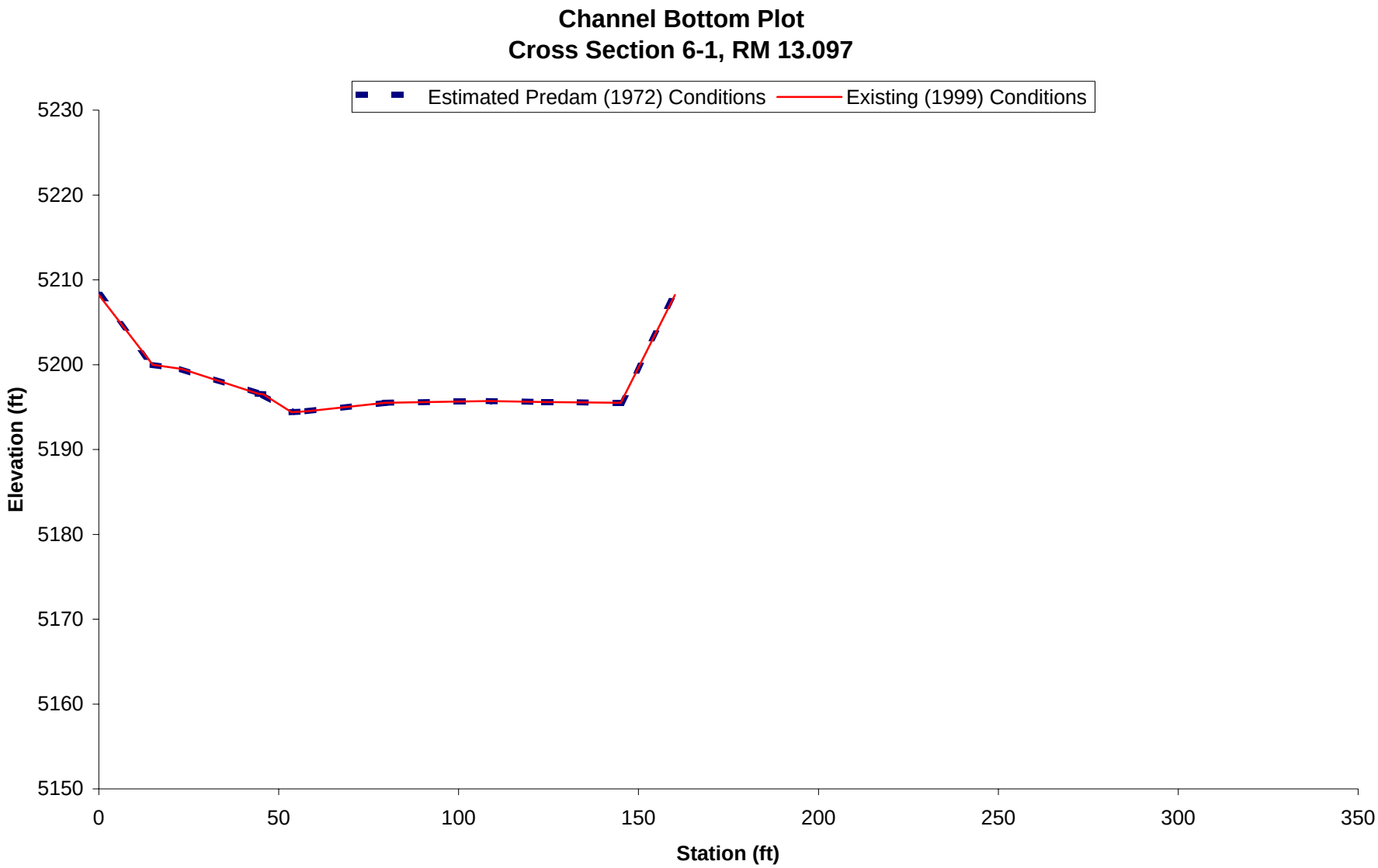
5240
5230
5220
5210
5200
5190
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-1, RM 13.097
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
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5200
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5180
5170
5160
5150
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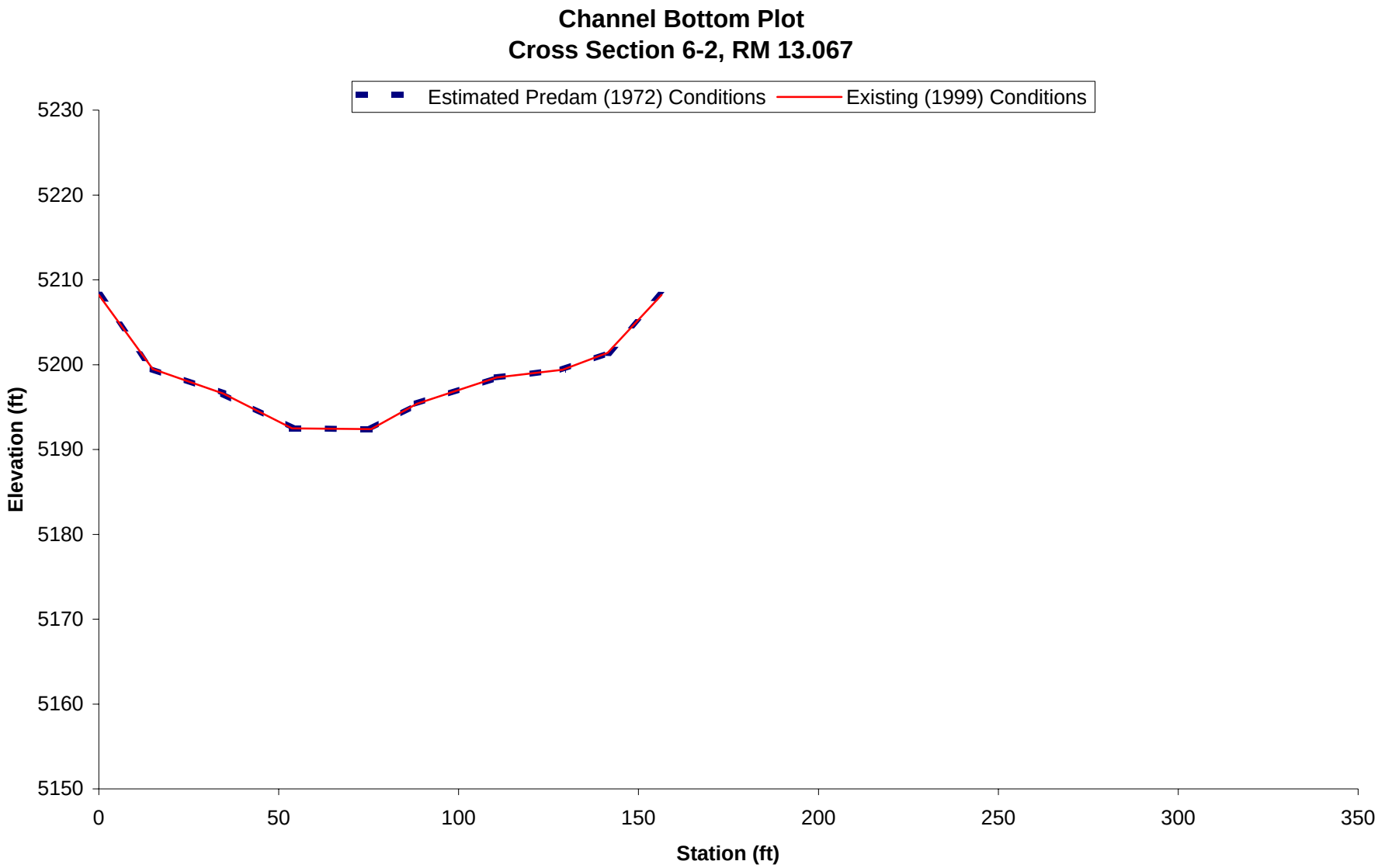
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-2, RM 13.067
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
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5190
5180
5170
5160
5150
0
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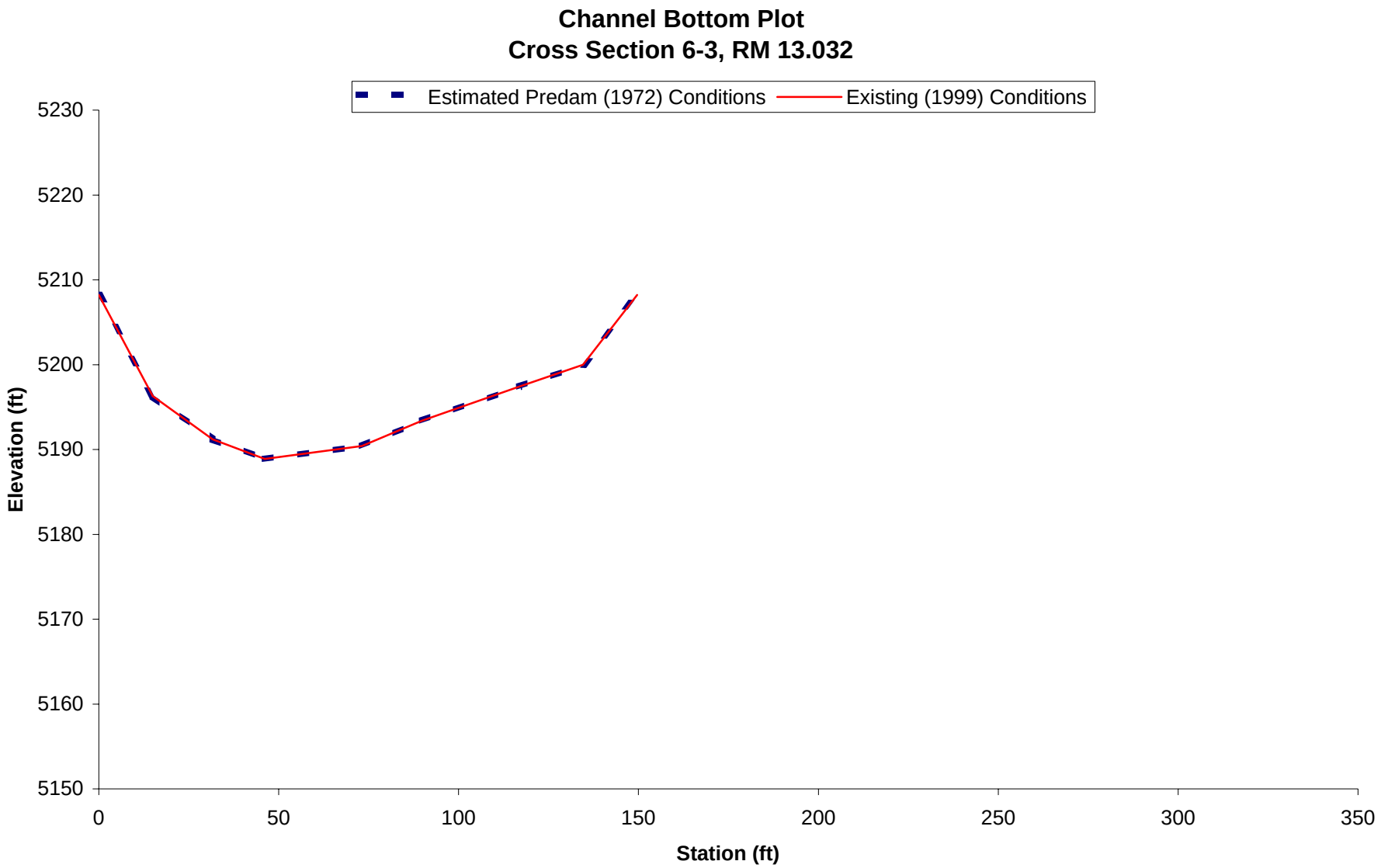
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-3, RM 13.032
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
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5180
5170
5160
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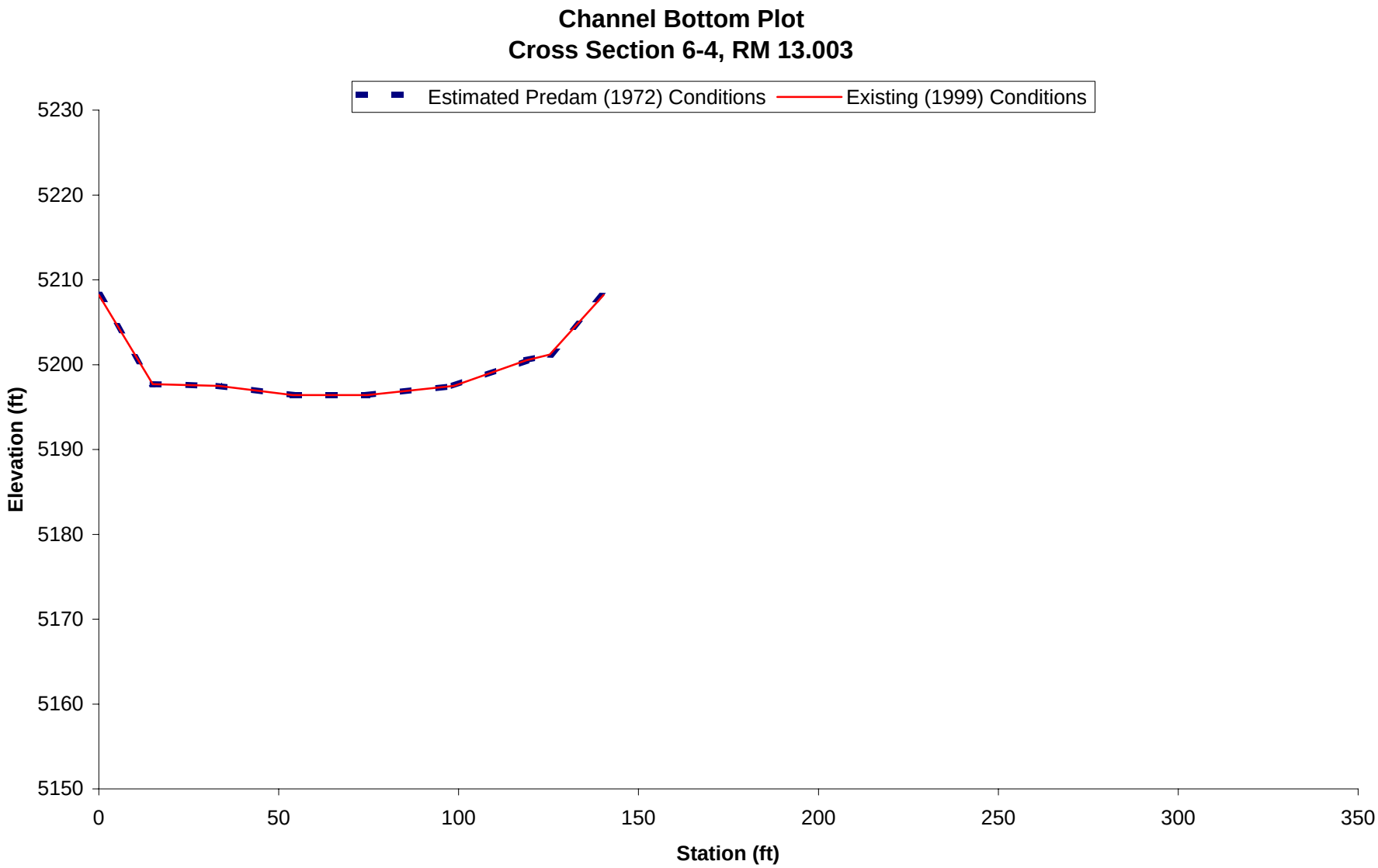
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-4, RM 13.003
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
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5160
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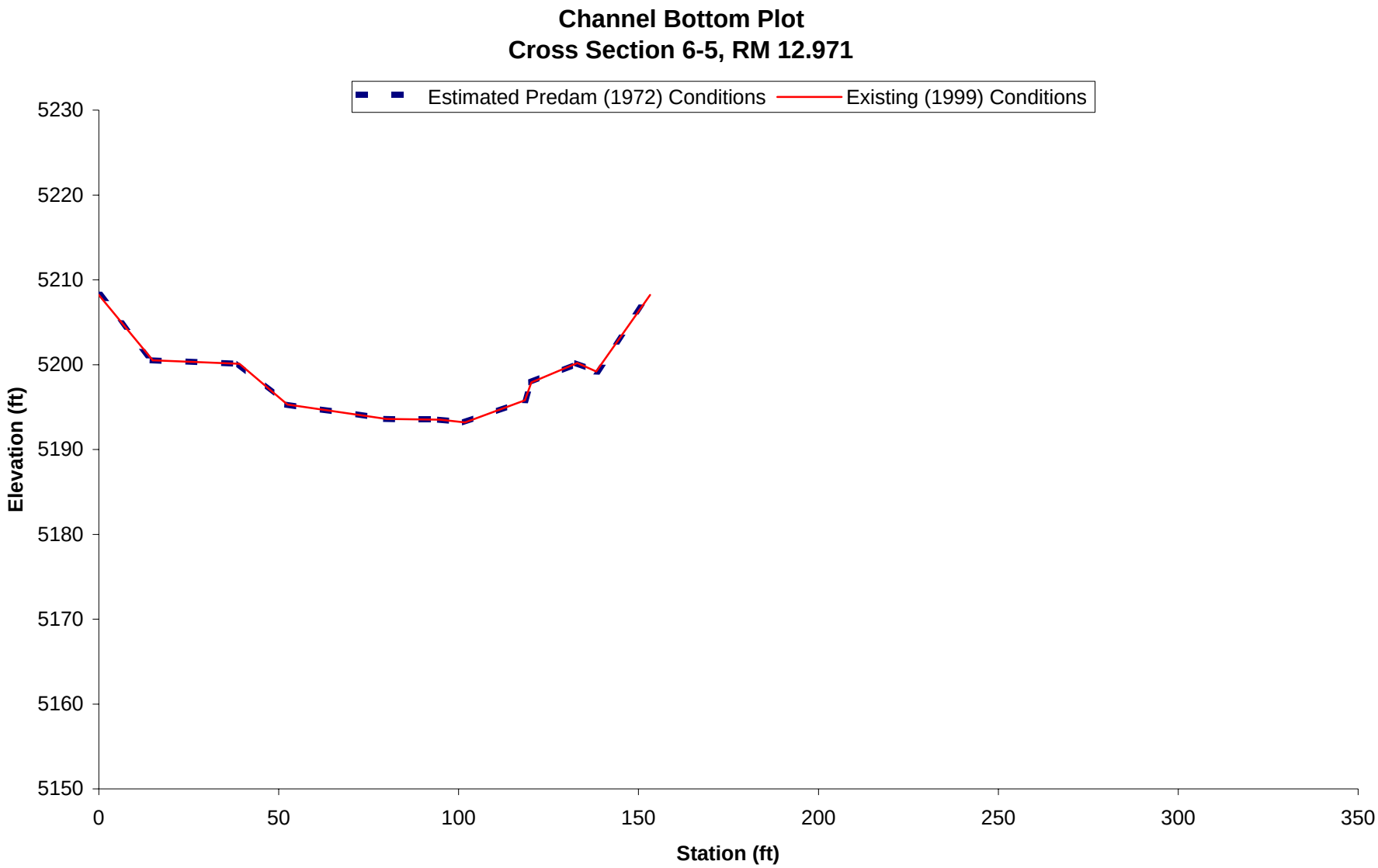
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-5, RM 12.971
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
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5180
5170
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5150
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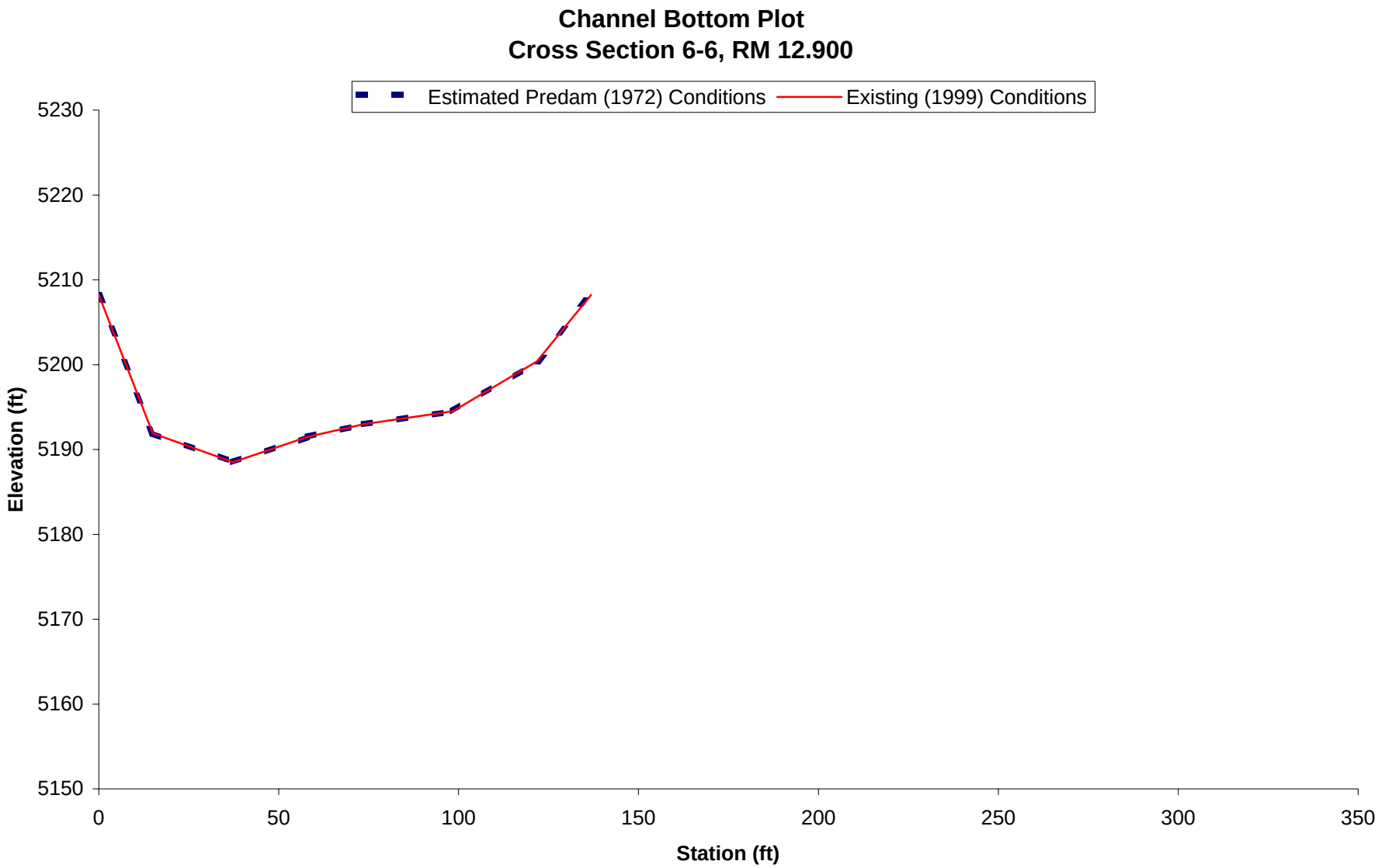
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-6, RM 12.900
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
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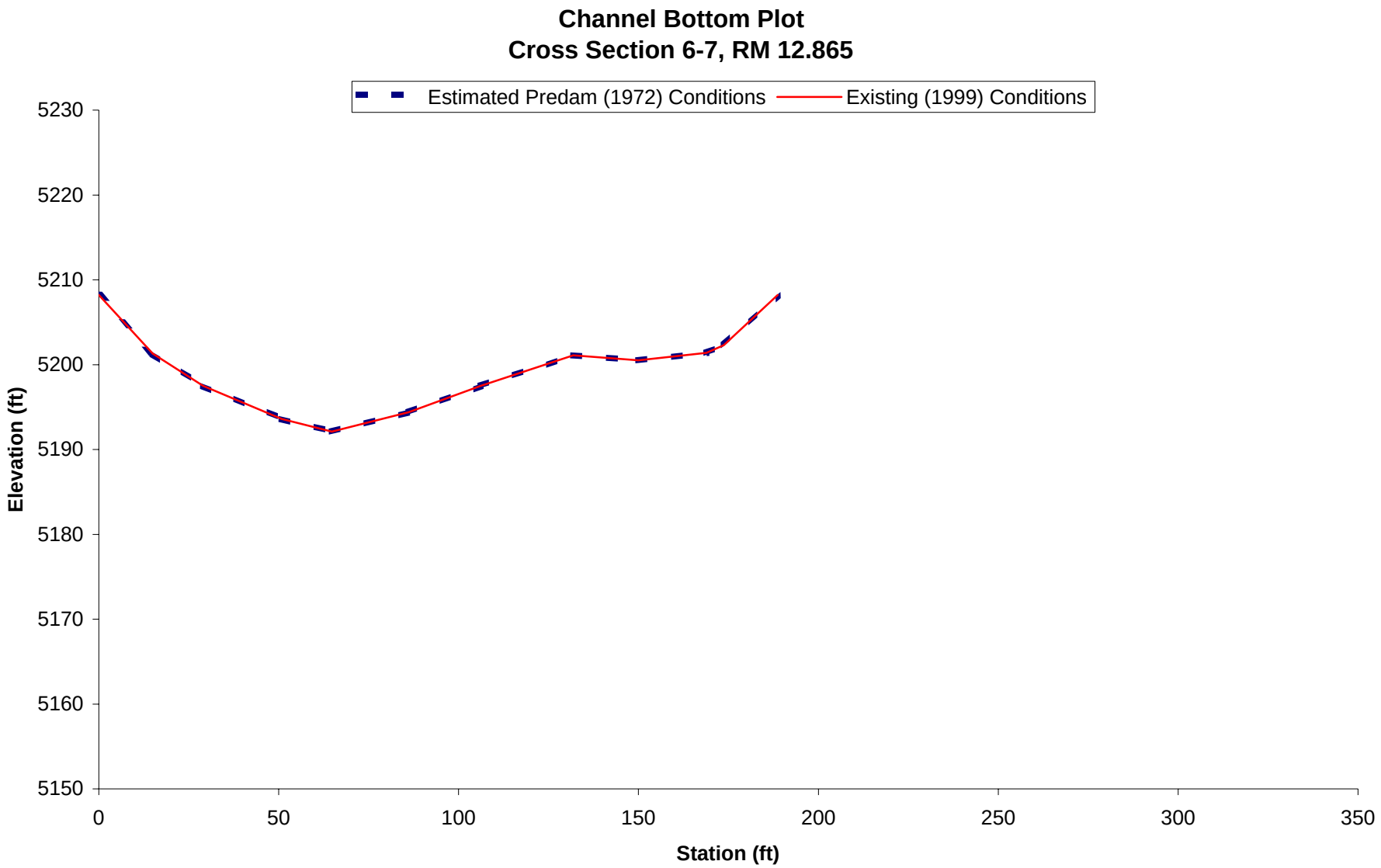
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-7, RM 12.865
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
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5200
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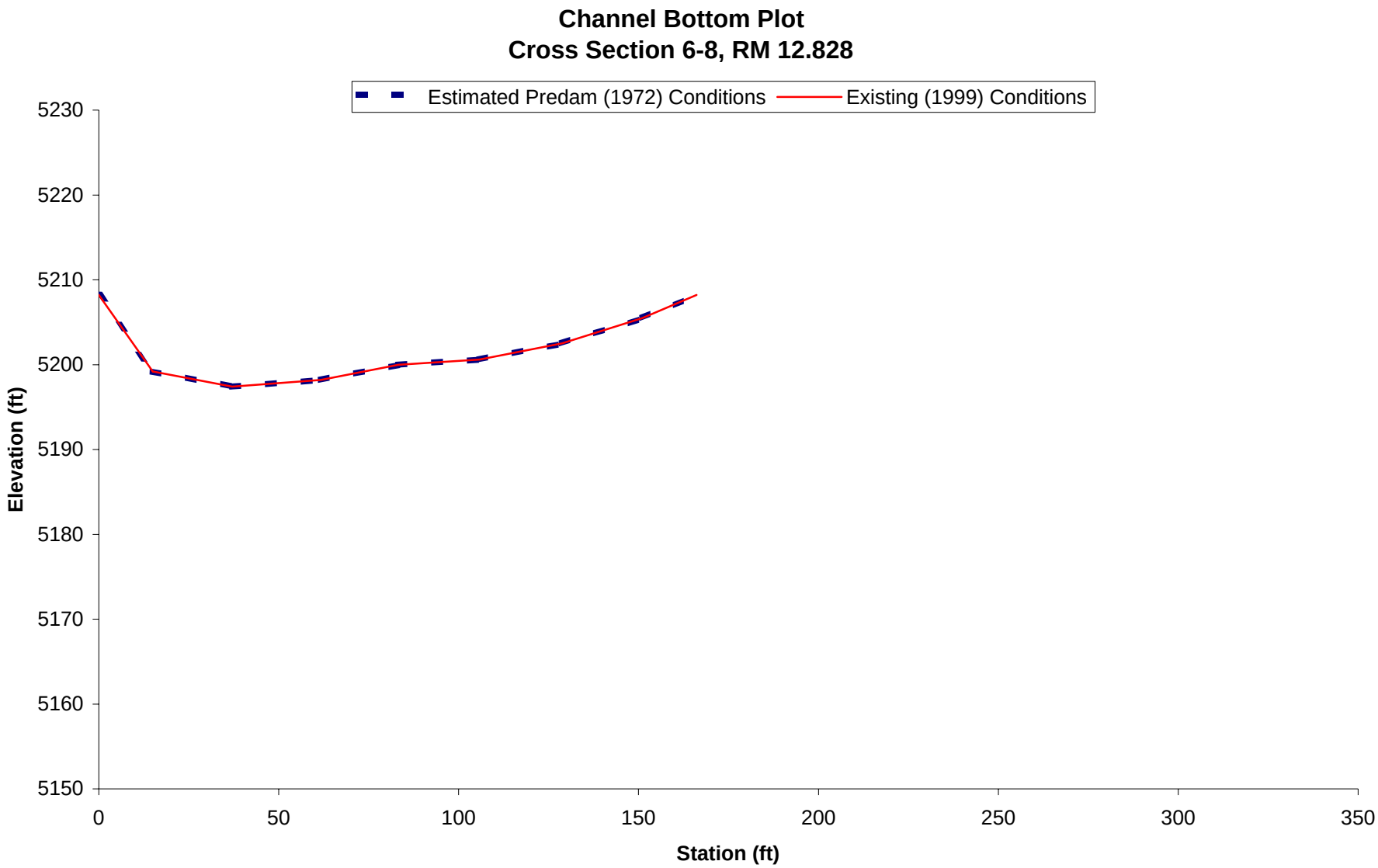
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-8, RM 12.828
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
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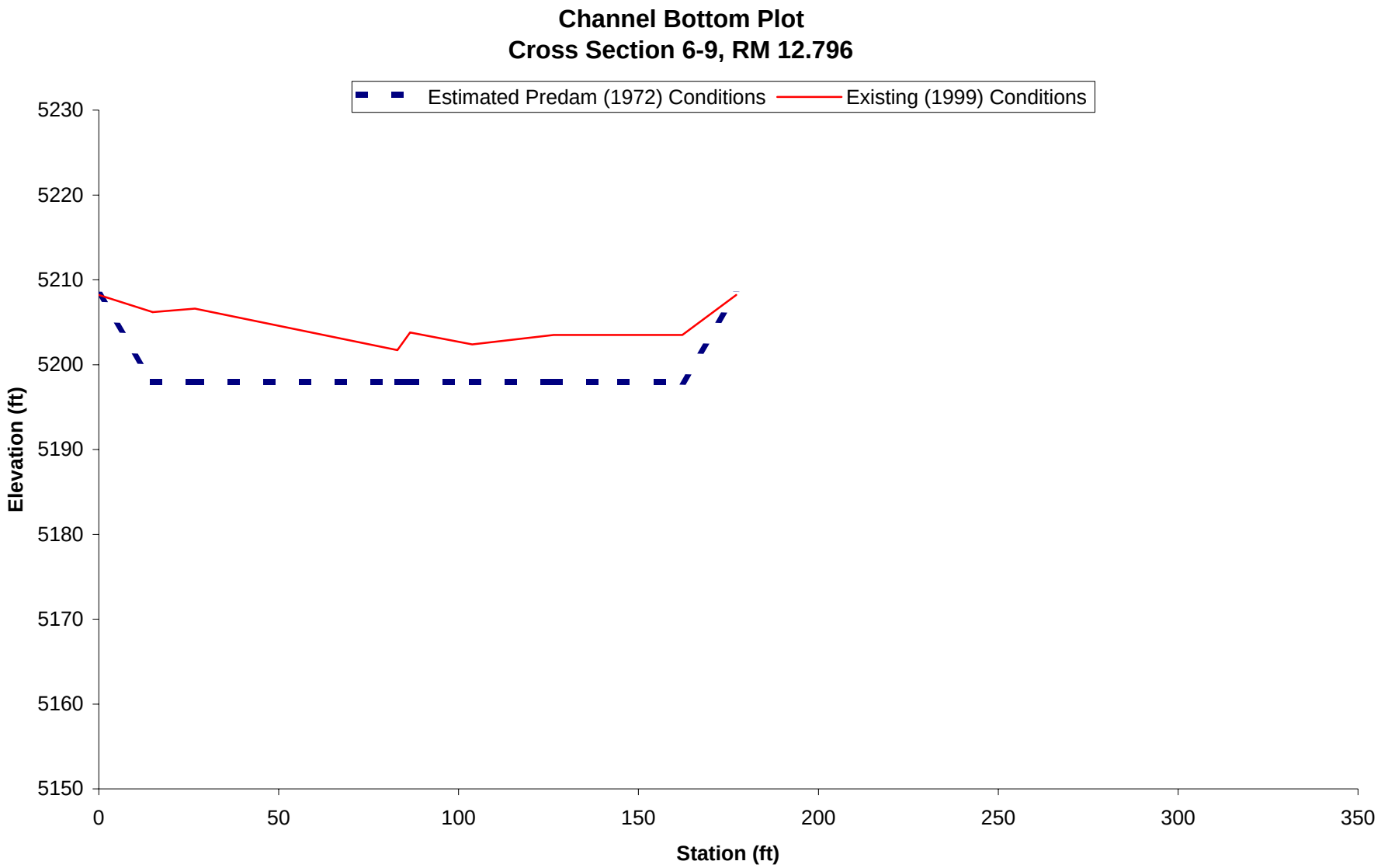
100
150
200
250
300
350
Station (ft)


Channel Bottom Plot
Cross Section 6-9, RM 12.796
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
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5180
5170
5160
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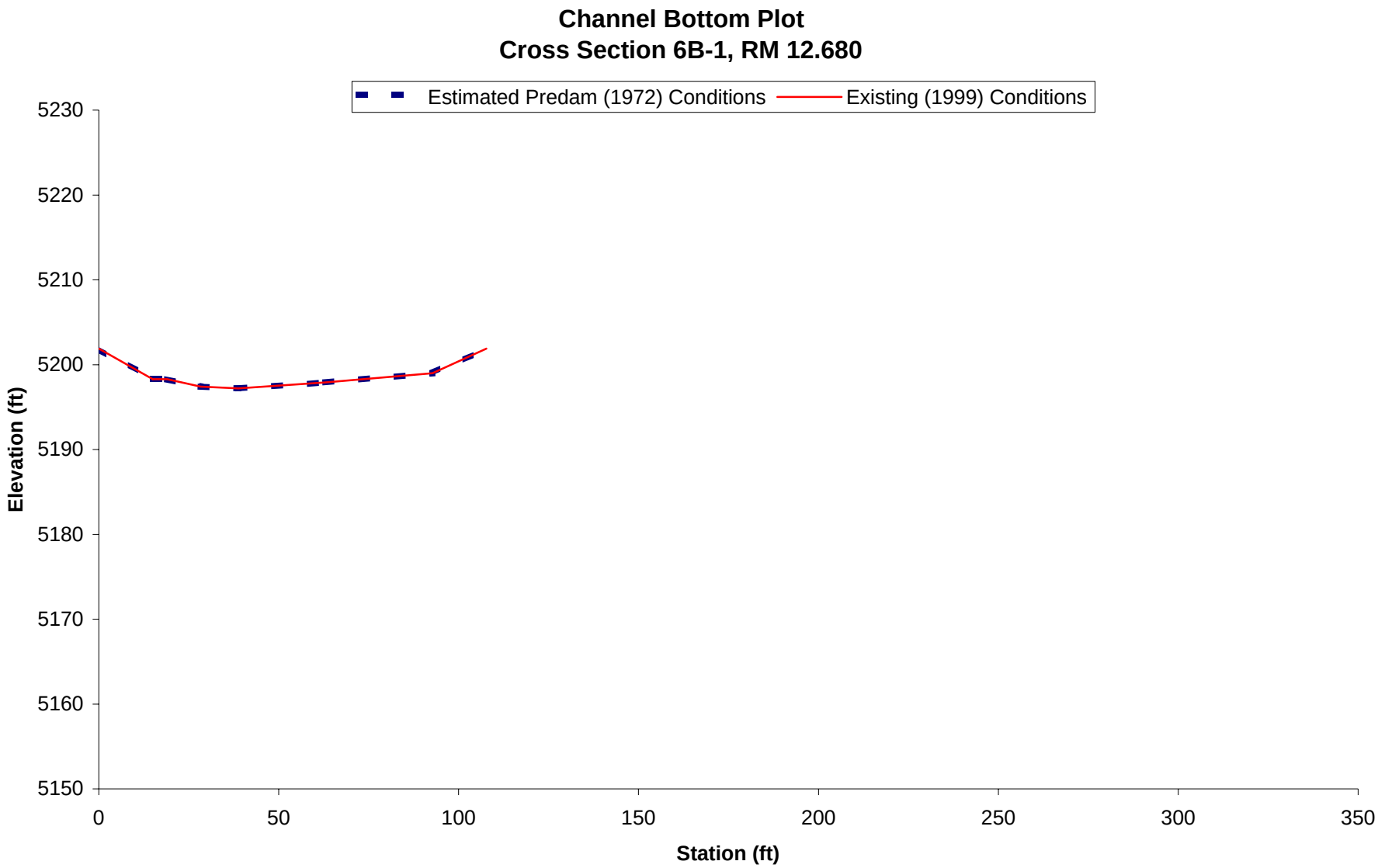
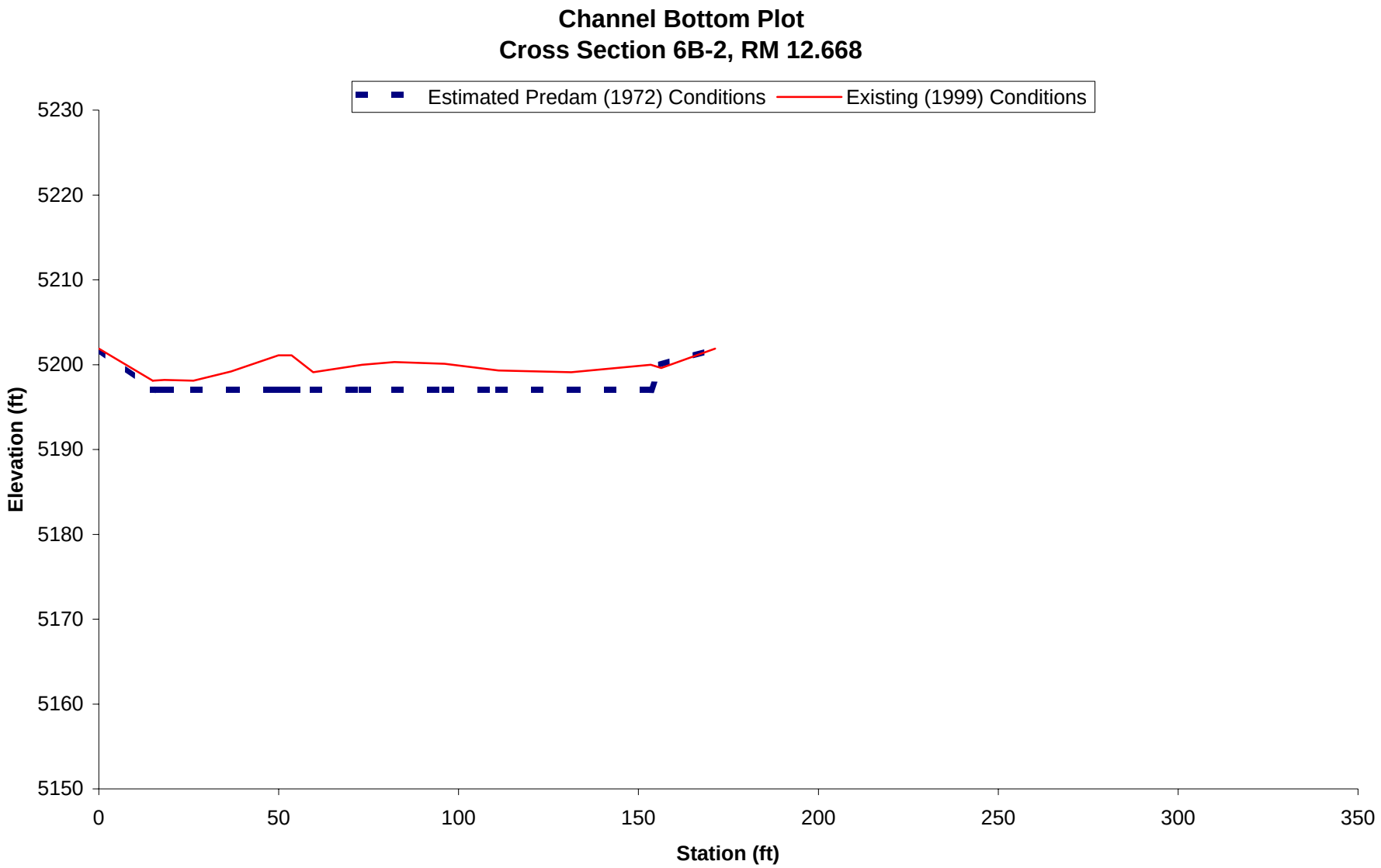
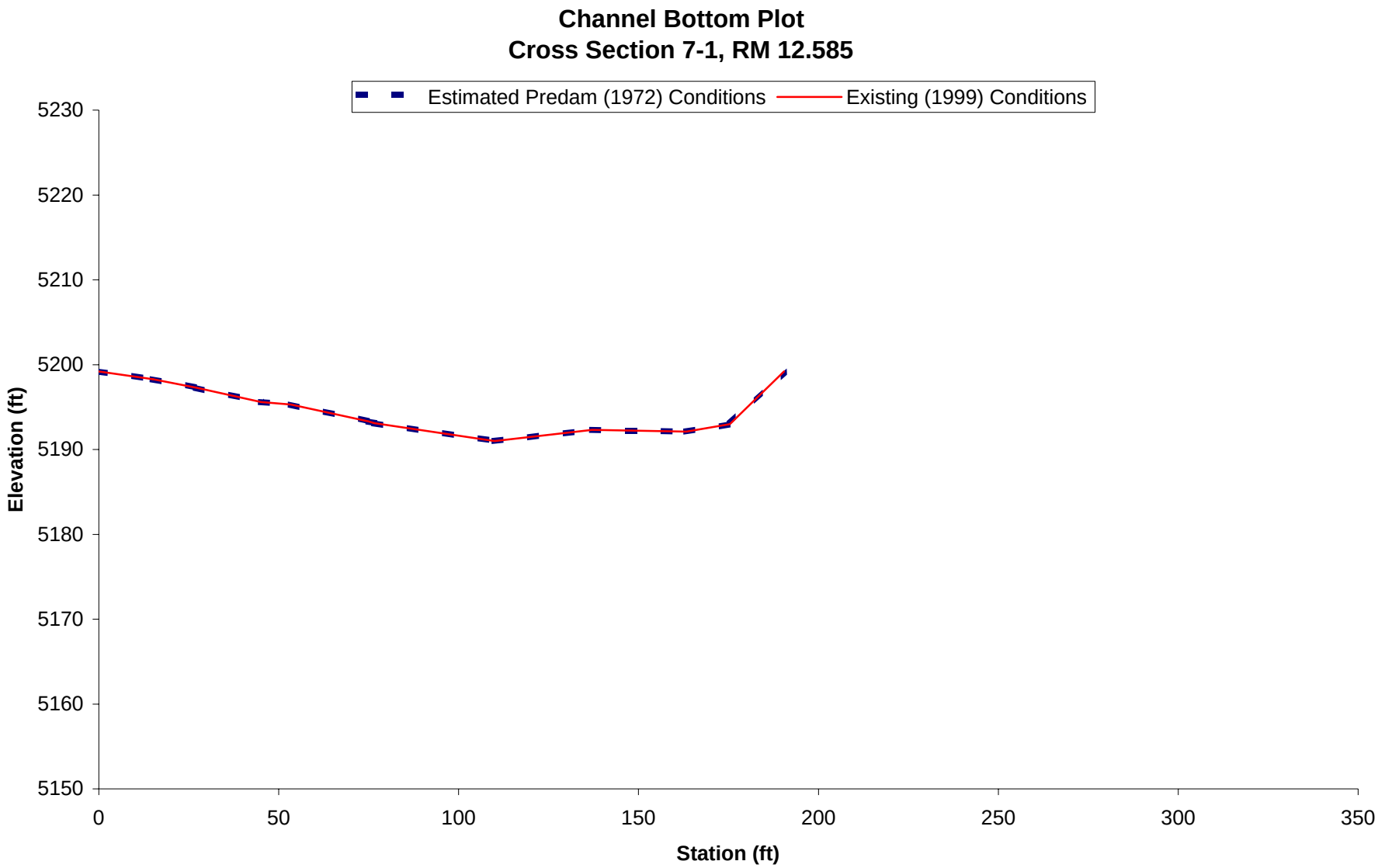
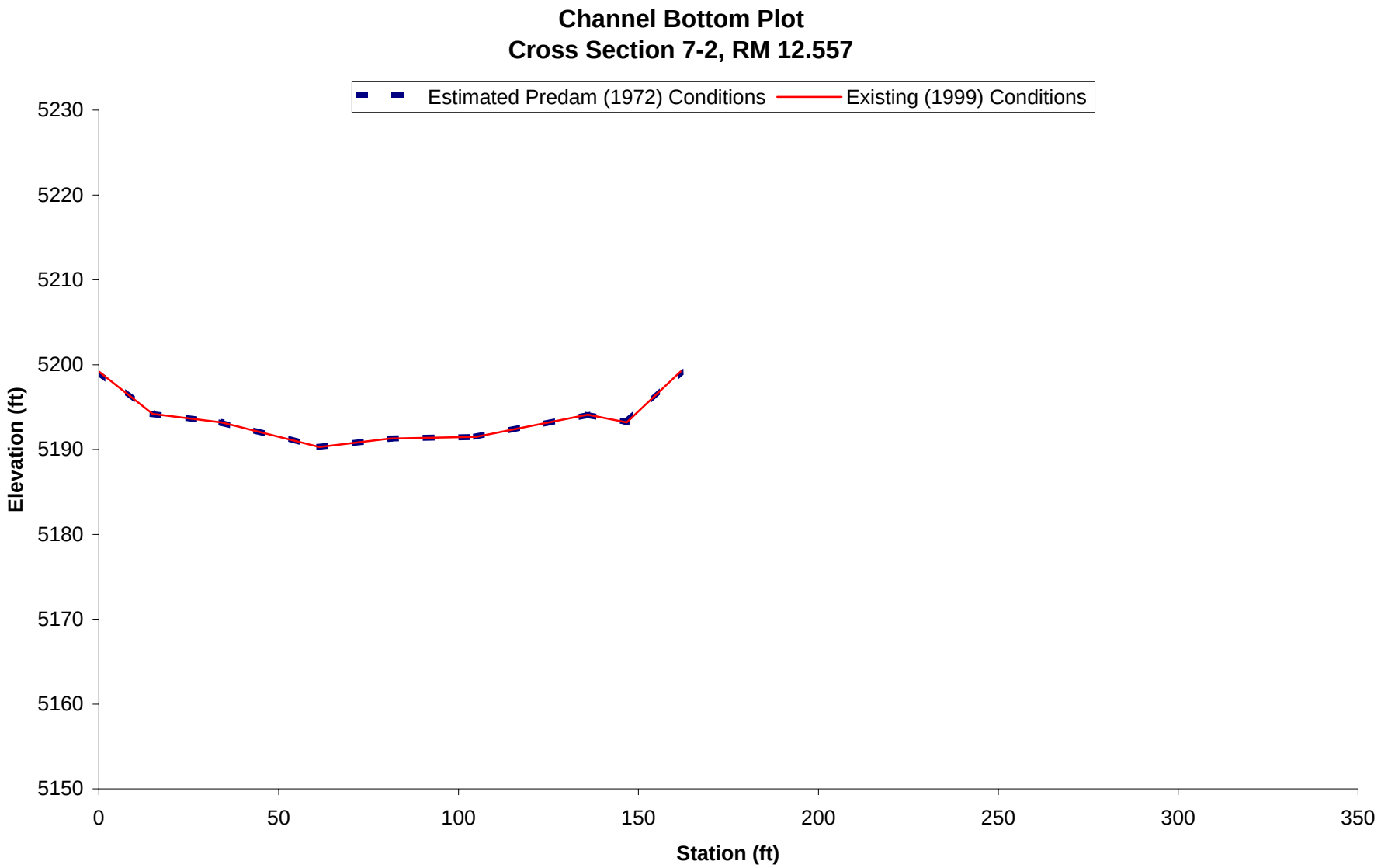
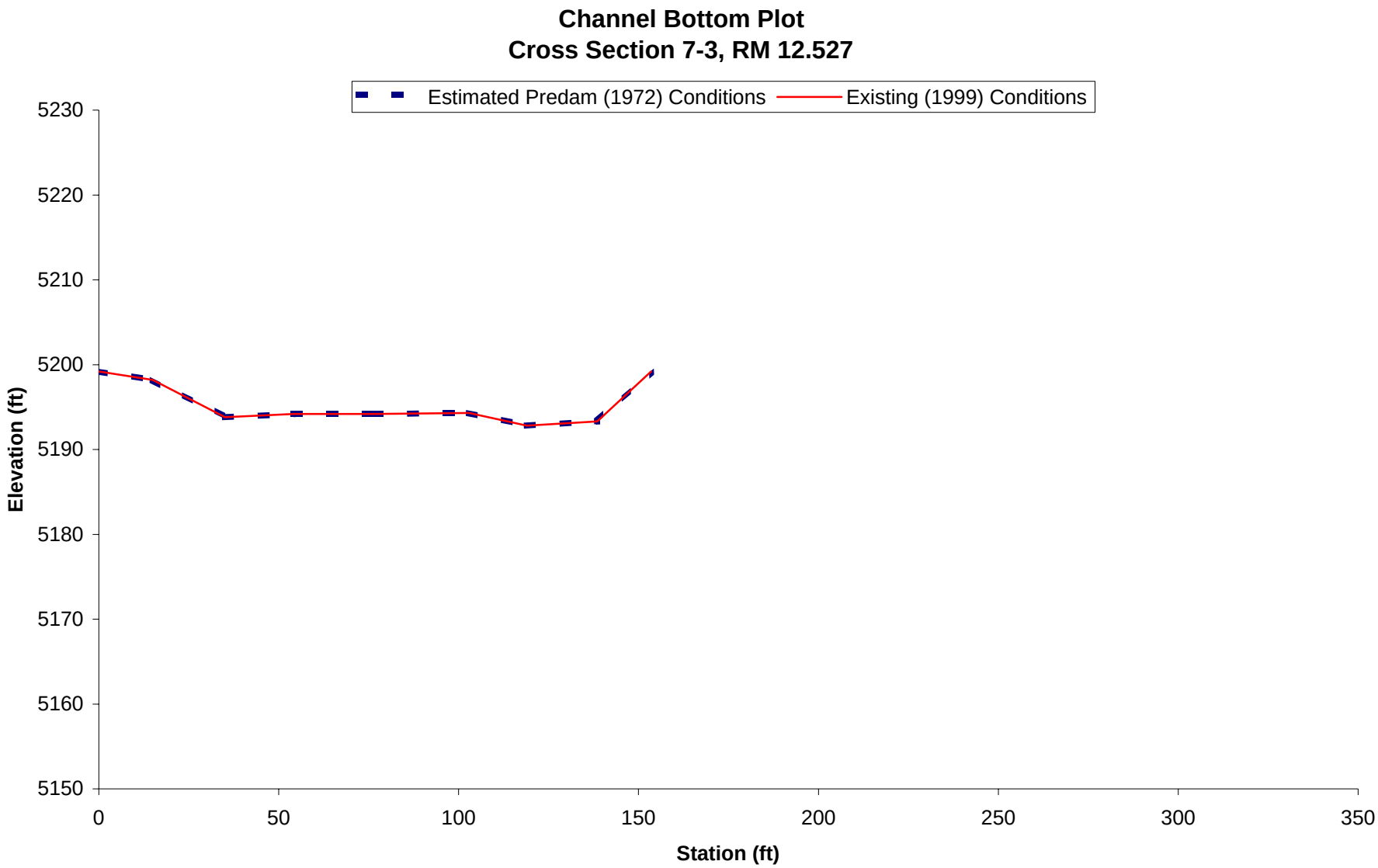
100
150
200
250
300
350
Station (ft)

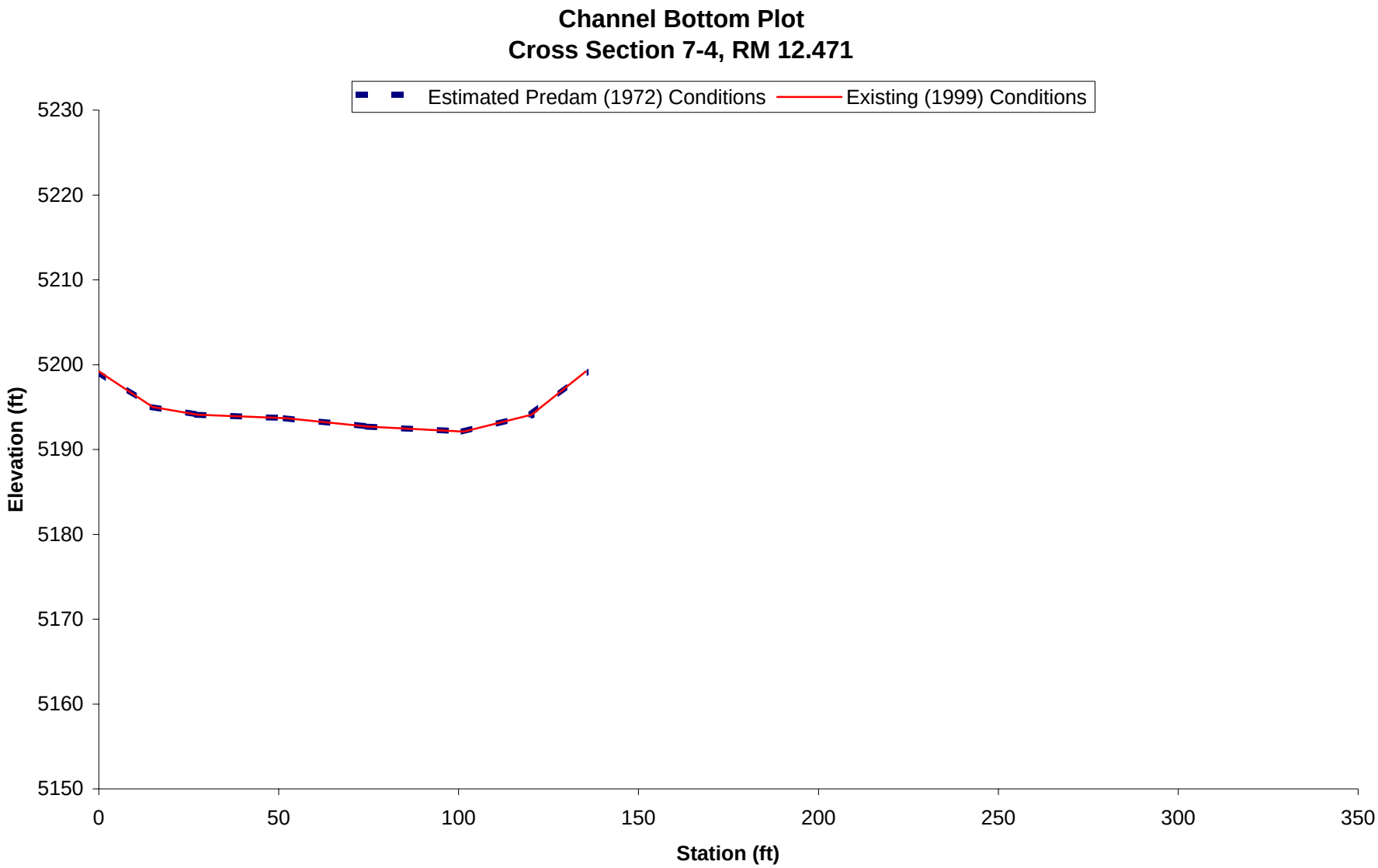

Channel Bottom Plot
Cross Section 6B-1, RM 12.680
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

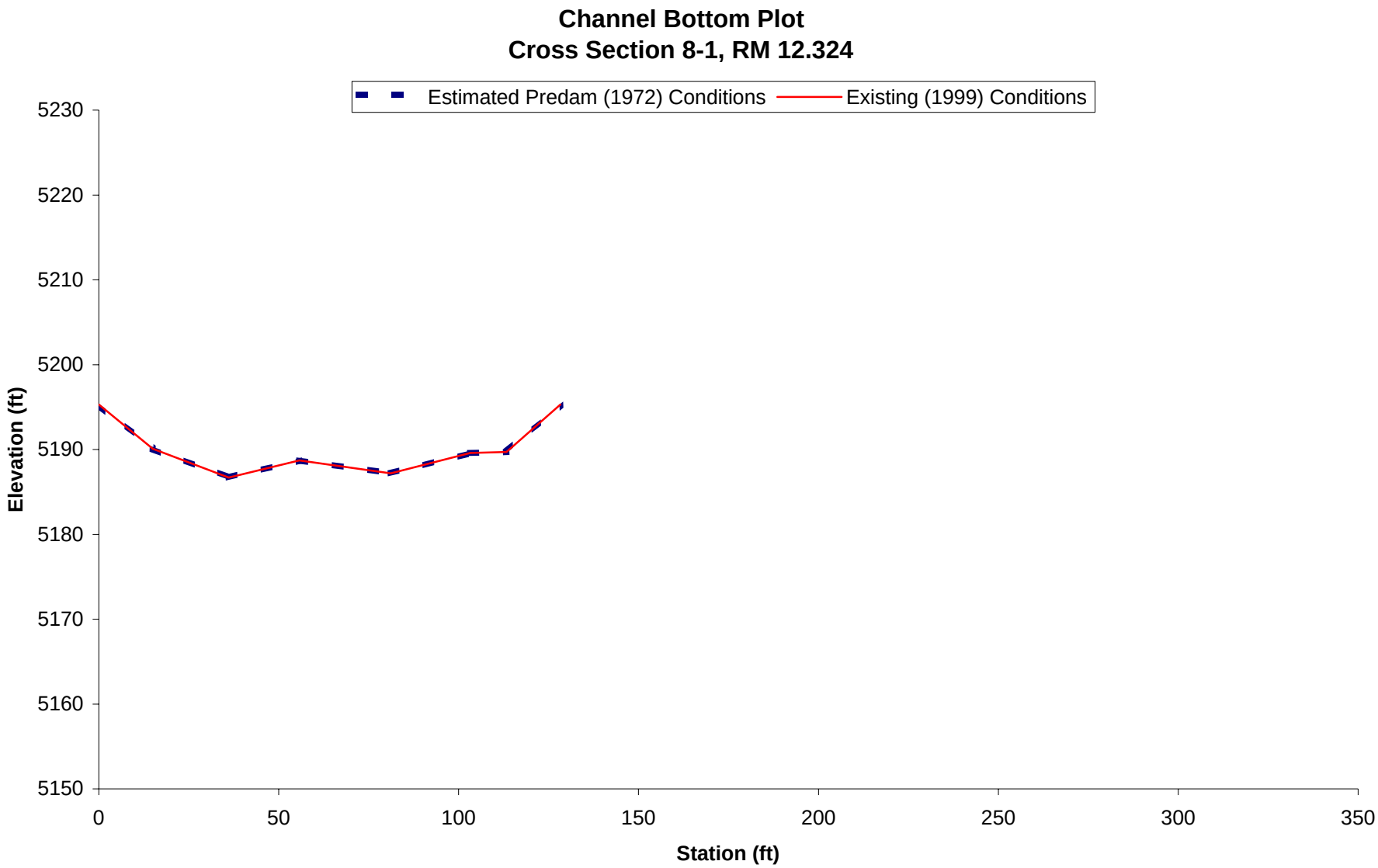

Channel Bottom Plot
Cross Section 6B-2, RM 12.668
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

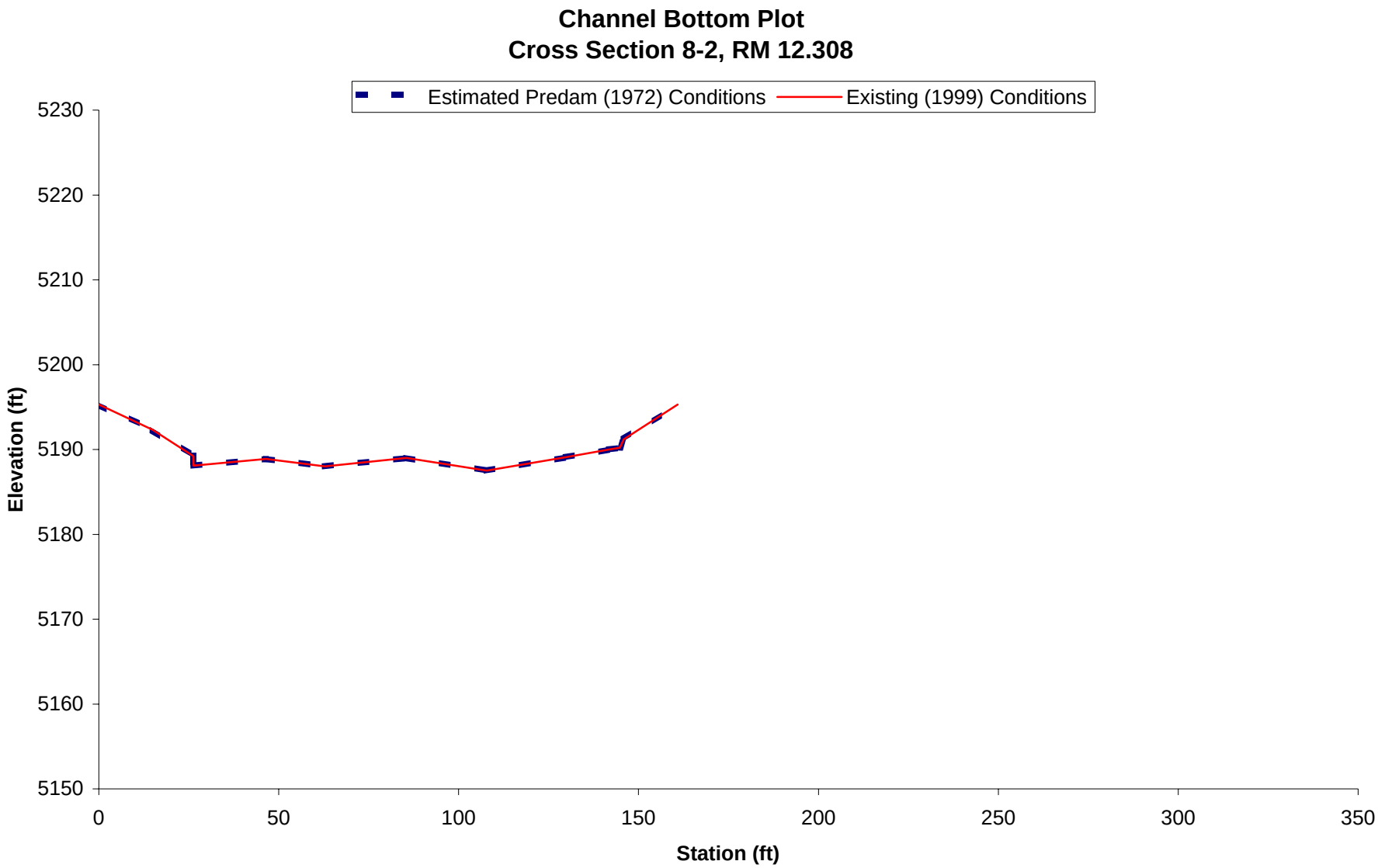

Channel Bottom Plot
Cross Section 7-1, RM 12.585
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

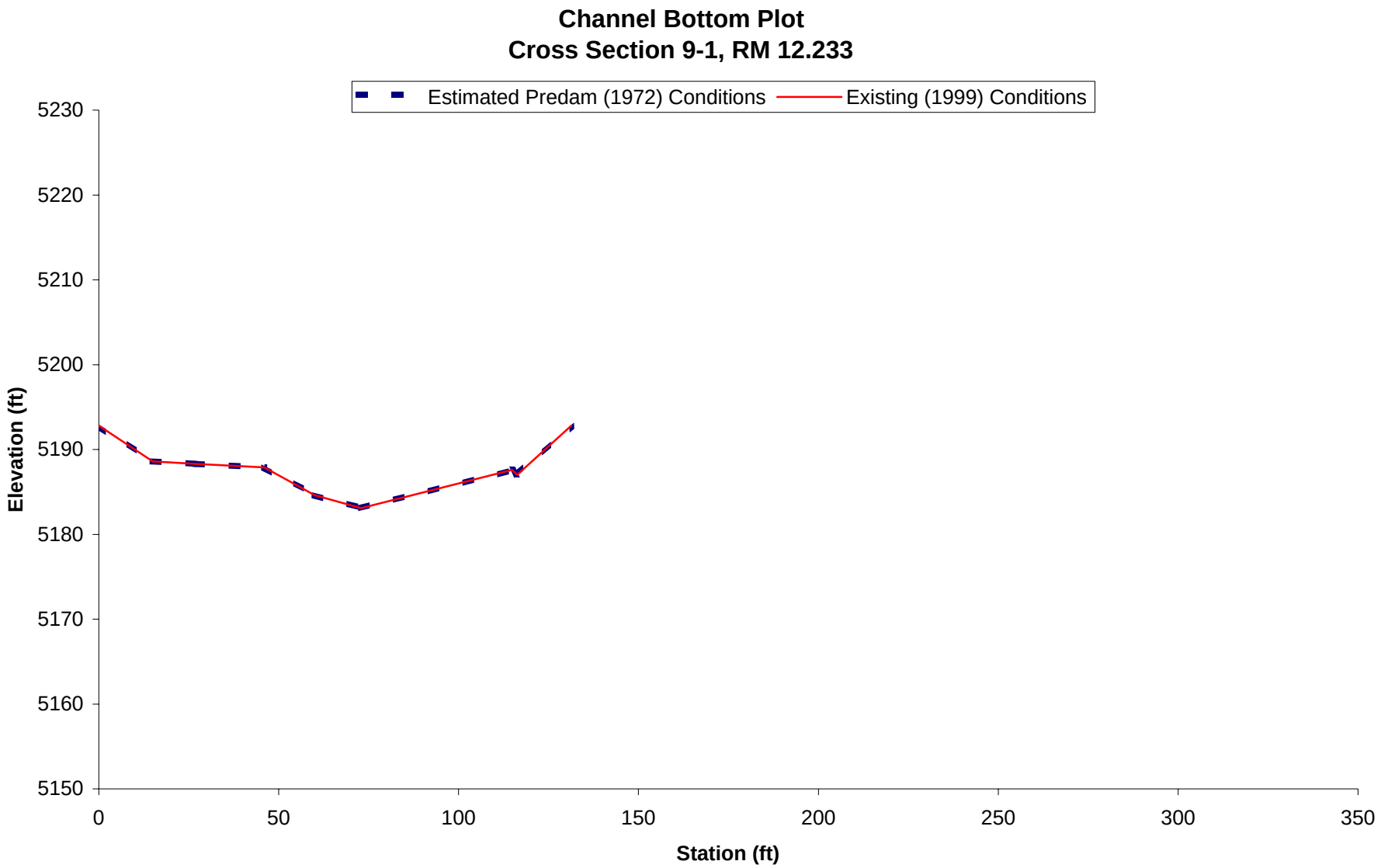

Channel Bottom Plot
Cross Section 7-2, RM 12.557
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

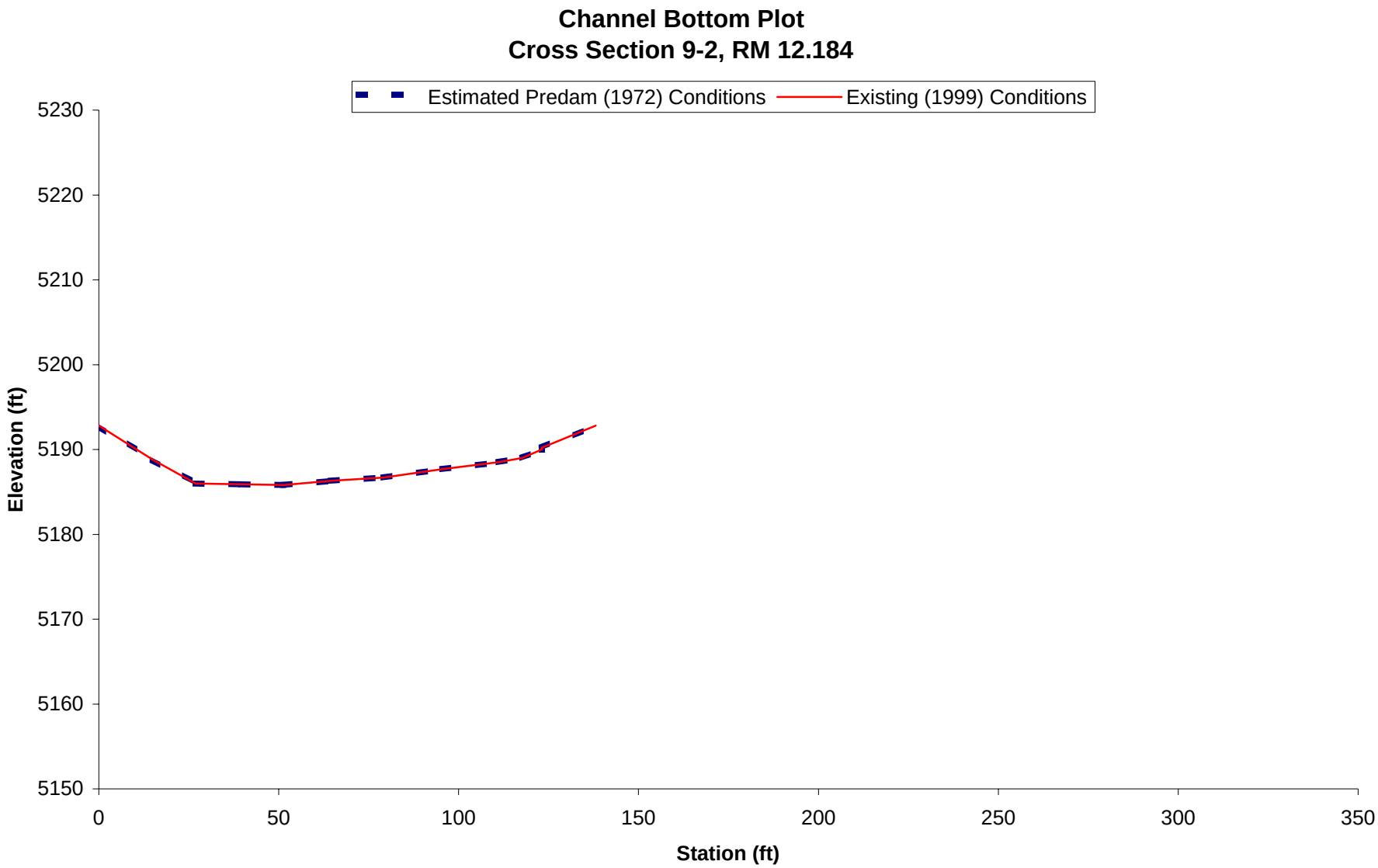

Channel Bottom Plot
Cross Section 7-3, RM 12.527
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

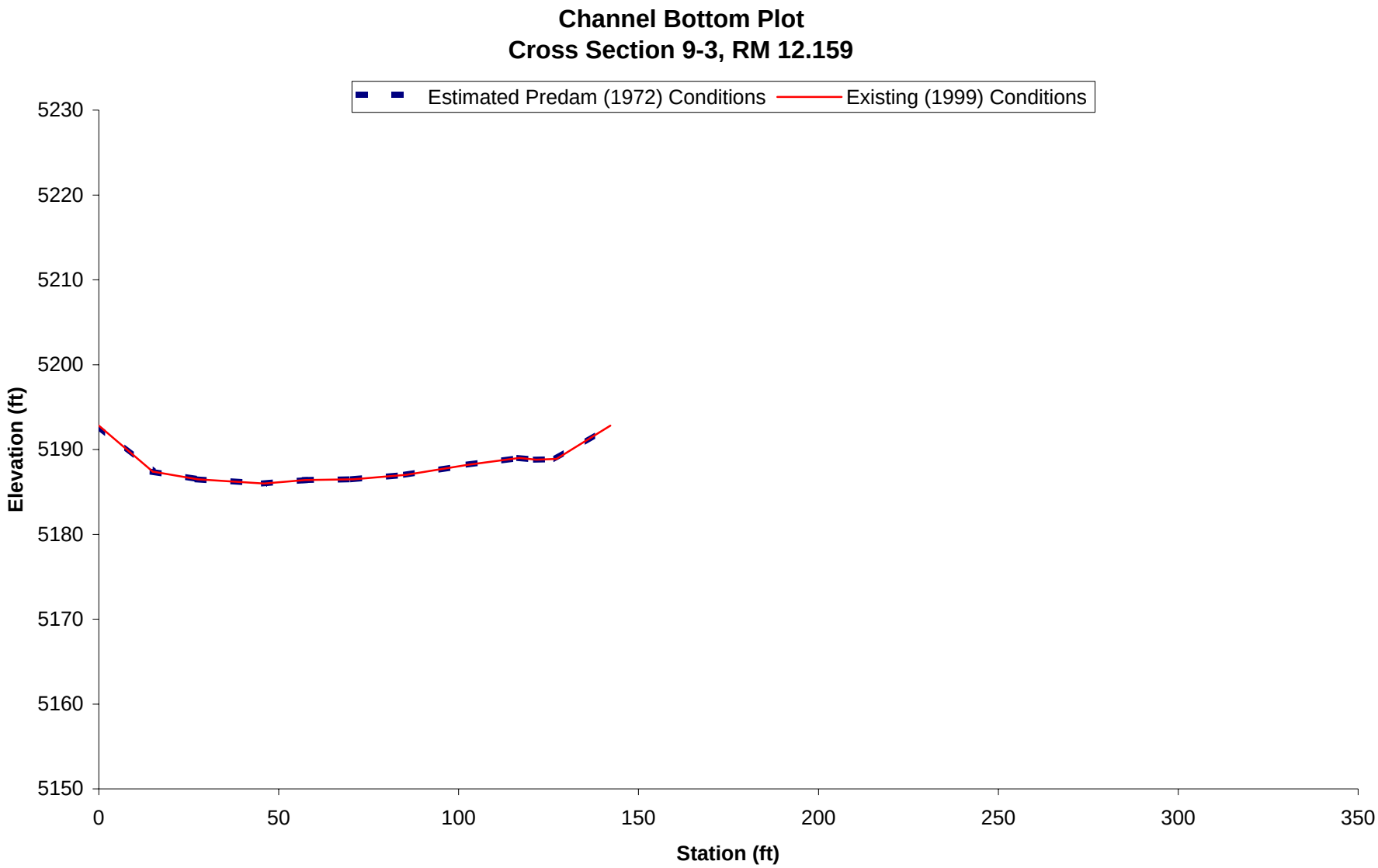

Channel Bottom Plot
Cross Section 7-4, RM 12.471
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

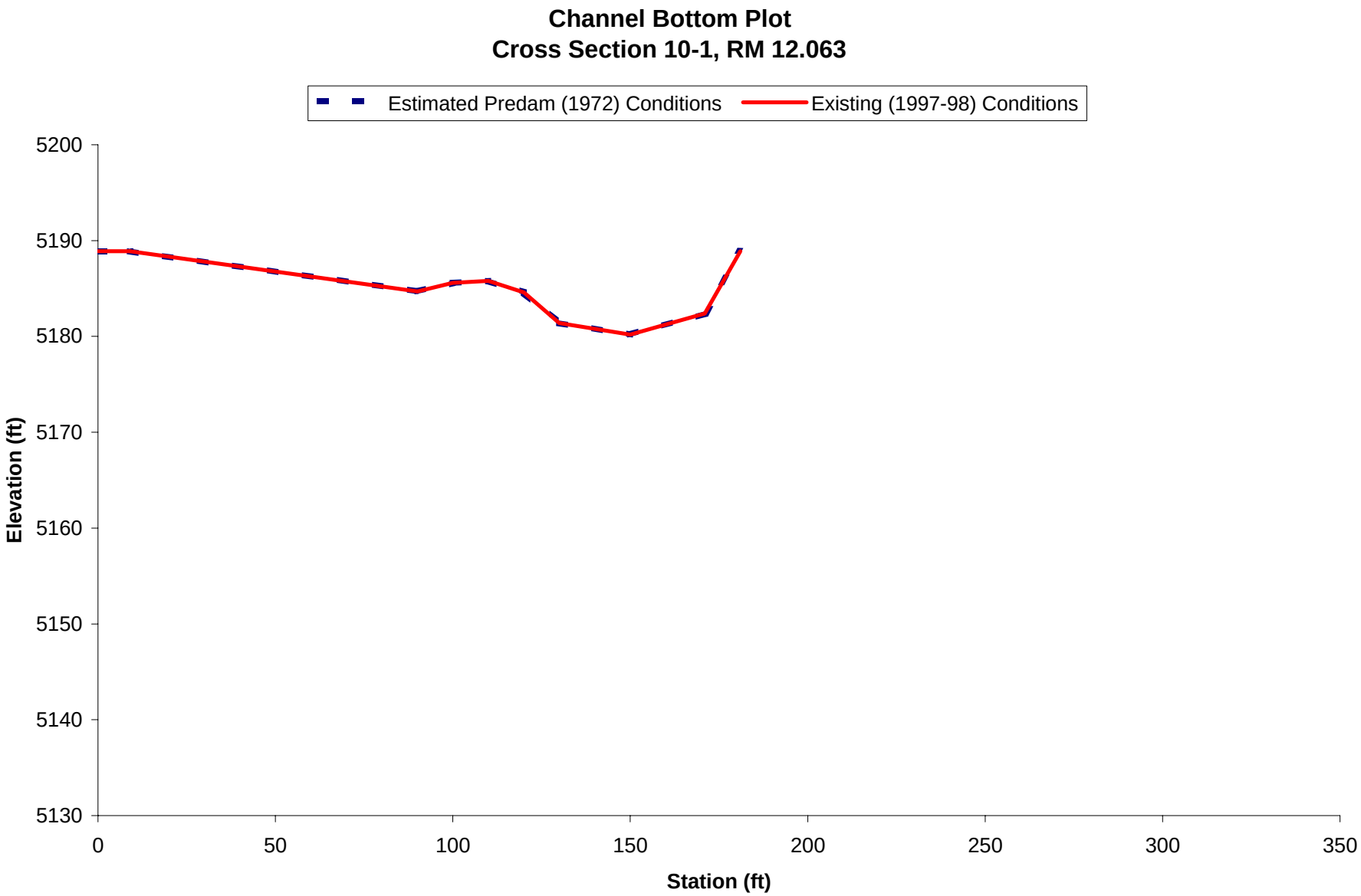

Channel Bottom Plot
Cross Section 8-1, RM 12.324
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

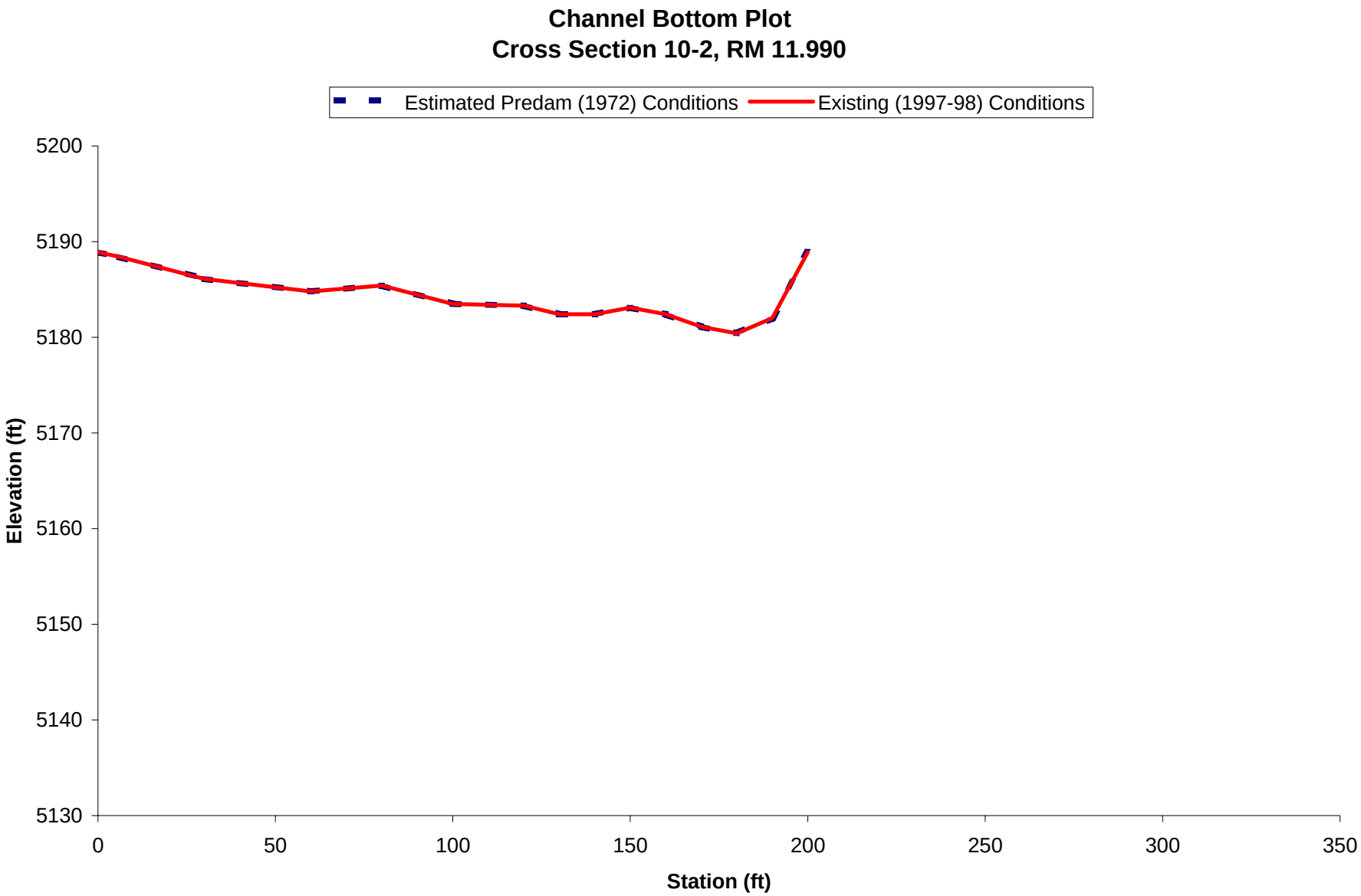

Channel Bottom Plot
Cross Section 8-2, RM 12.308
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

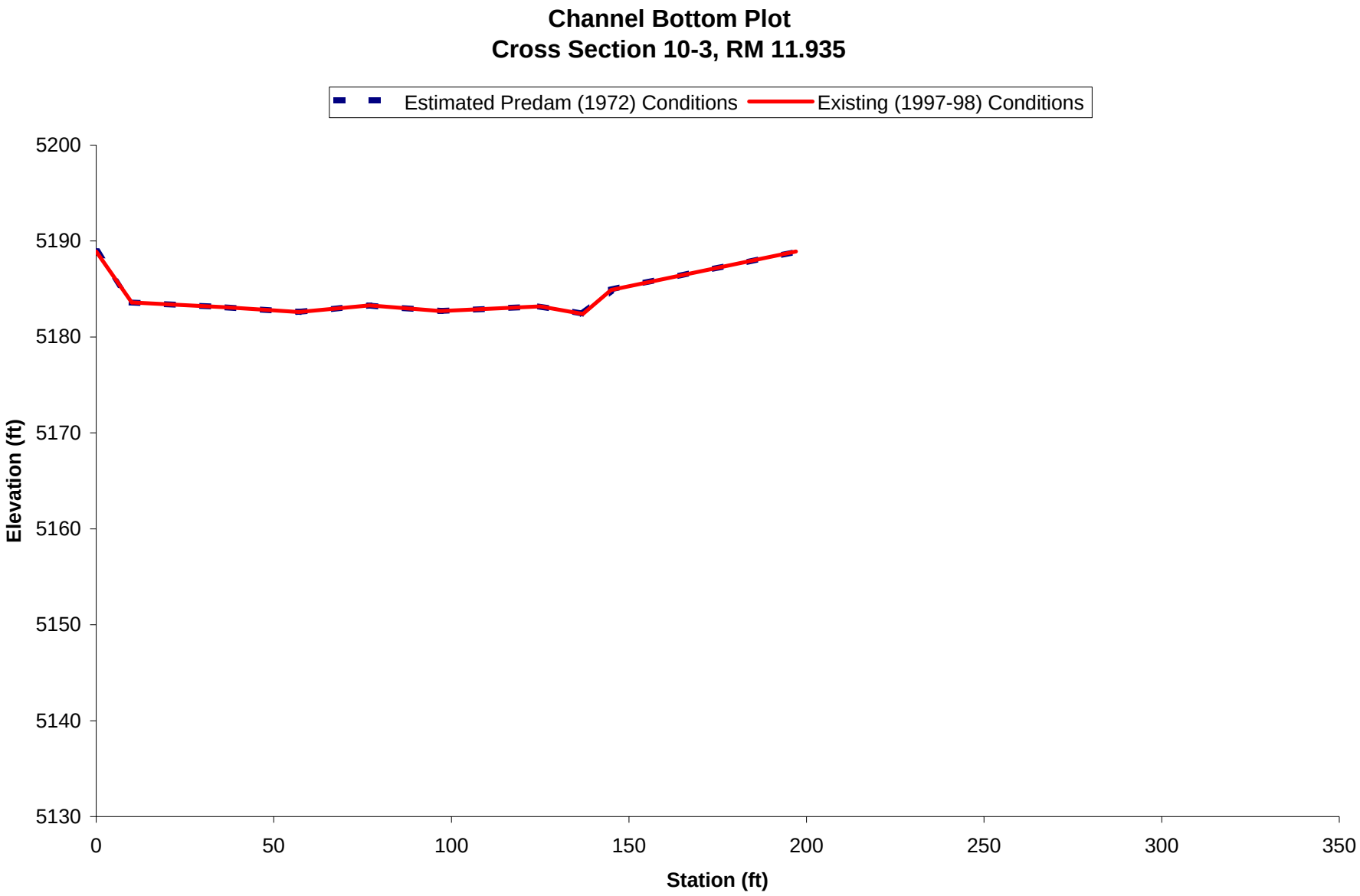

Channel Bottom Plot
Cross Section 9-1, RM 12.233
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

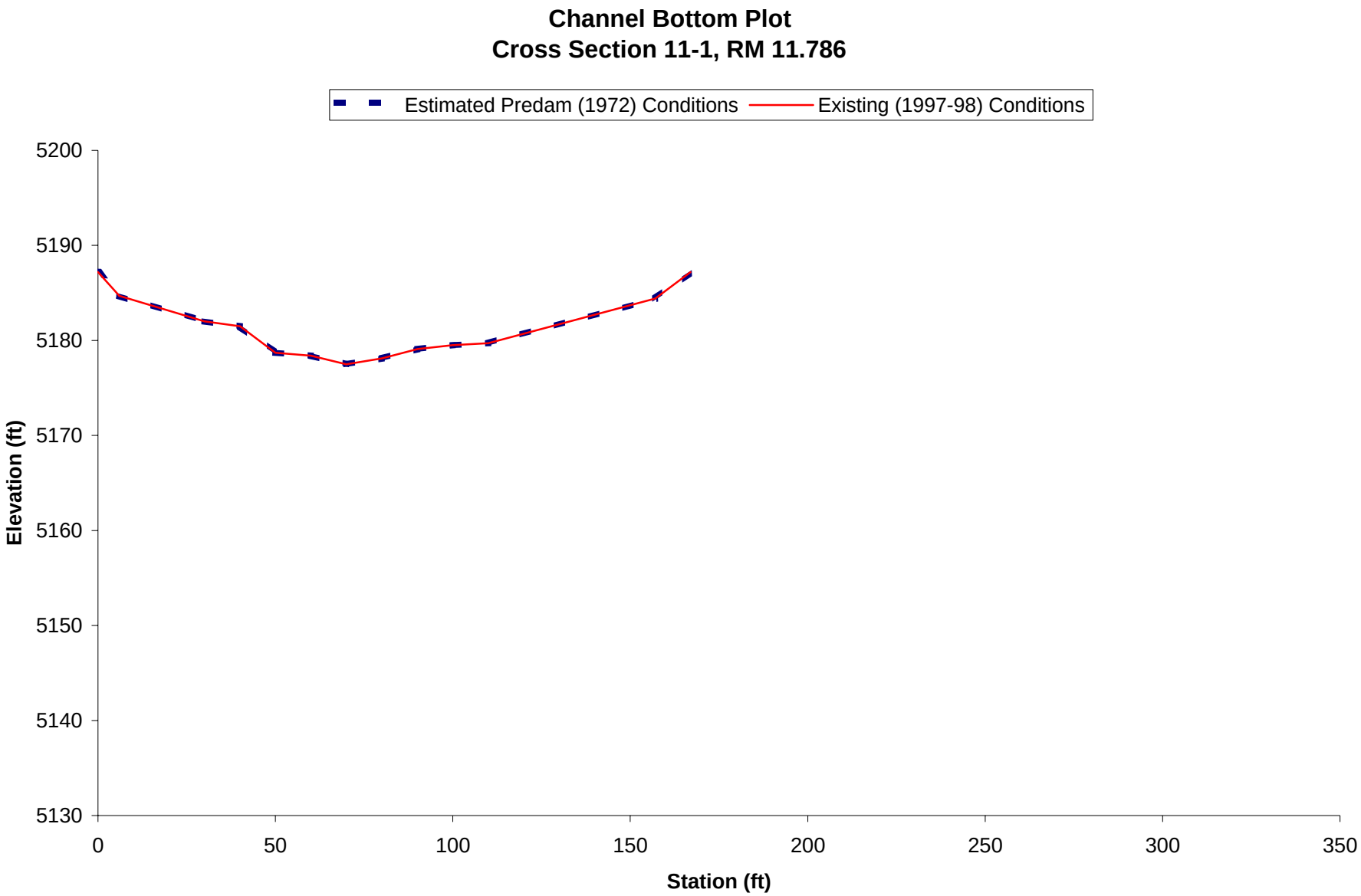

Channel Bottom Plot
Cross Section 9-2, RM 12.184
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

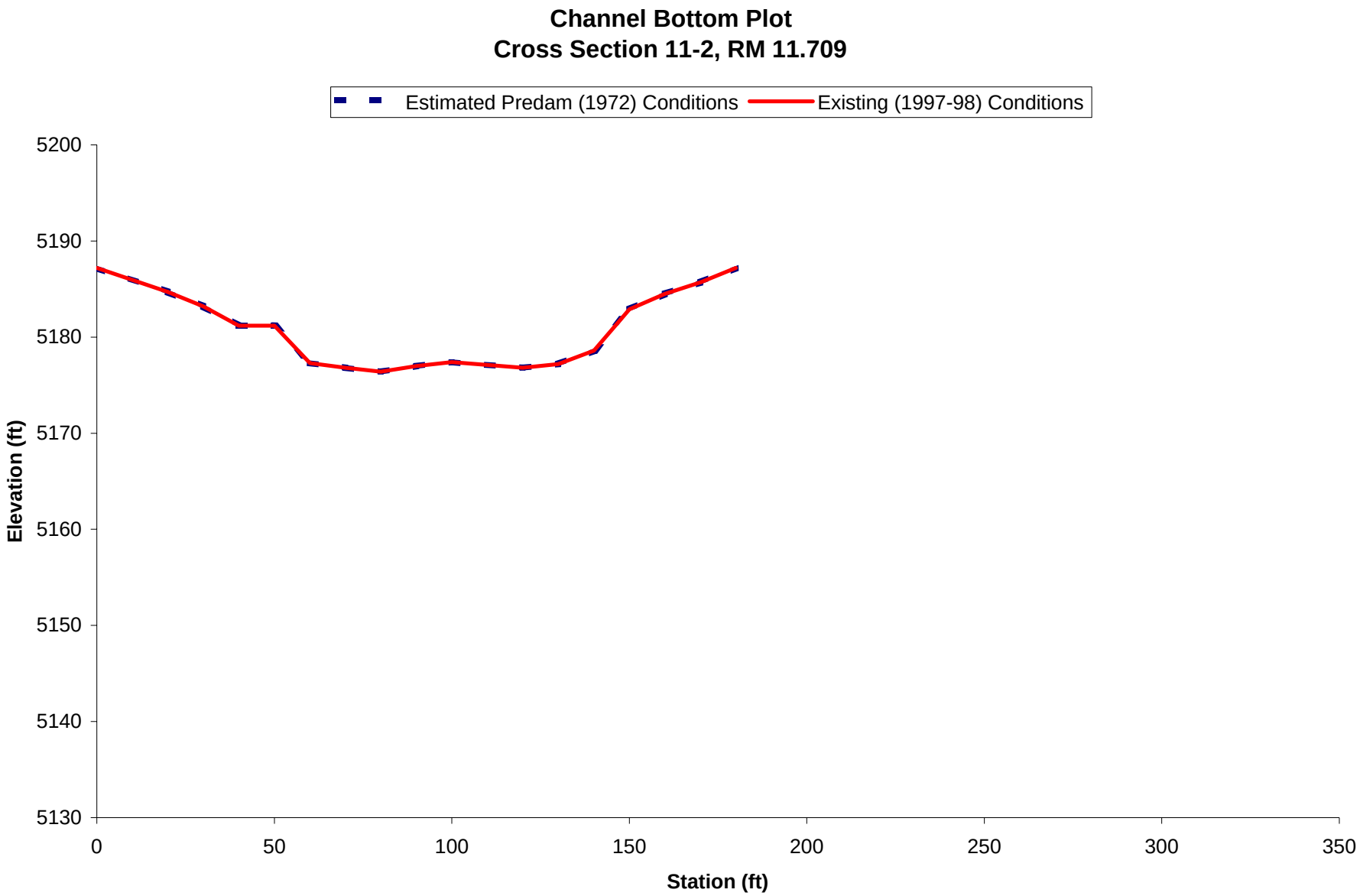

Channel Bottom Plot
Cross Section 9-3, RM 12.159
Estimated Predam (1972) Conditions
Existing (1999) Conditions
Elevation (ft)
5230
5220
5210
5200
5190
5180
5170
5160
5150
0
50
100
150
200
250
300
350
Station (ft)

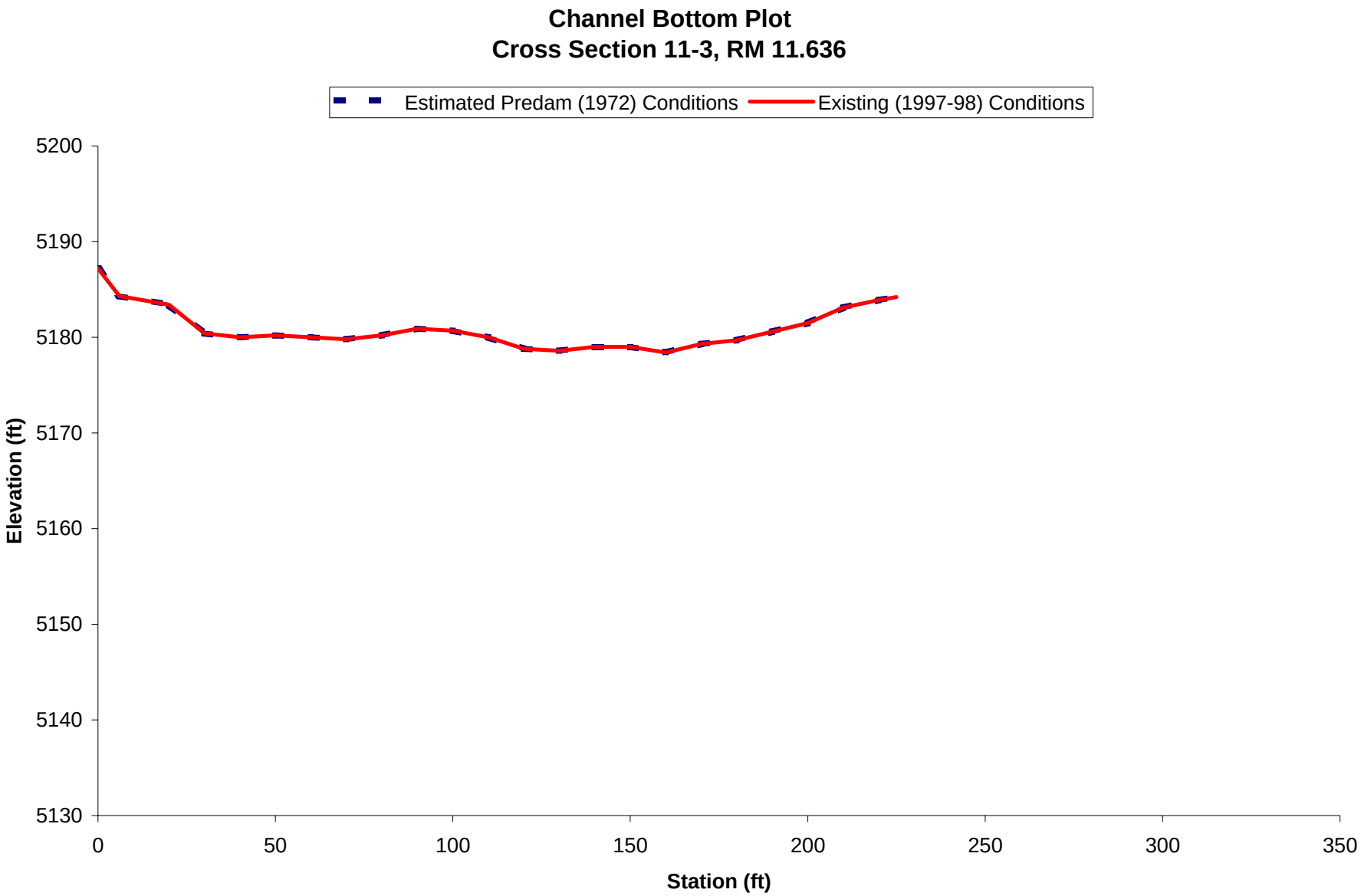

Channel Bottom Plot
Cross Section 10-1, RM 12.063
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

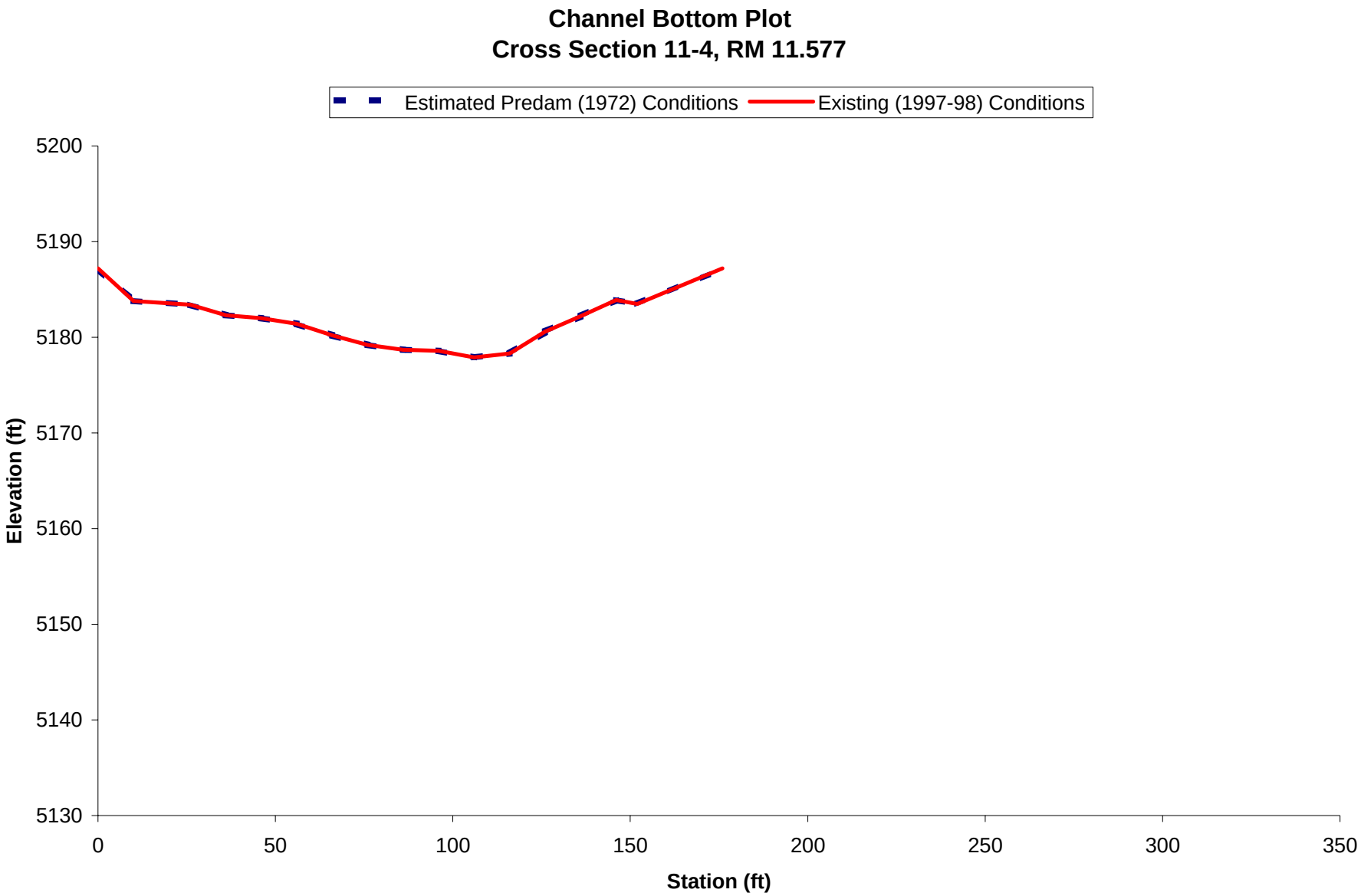

Channel Bottom Plot
Cross Section 10-2, RM 11.990
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

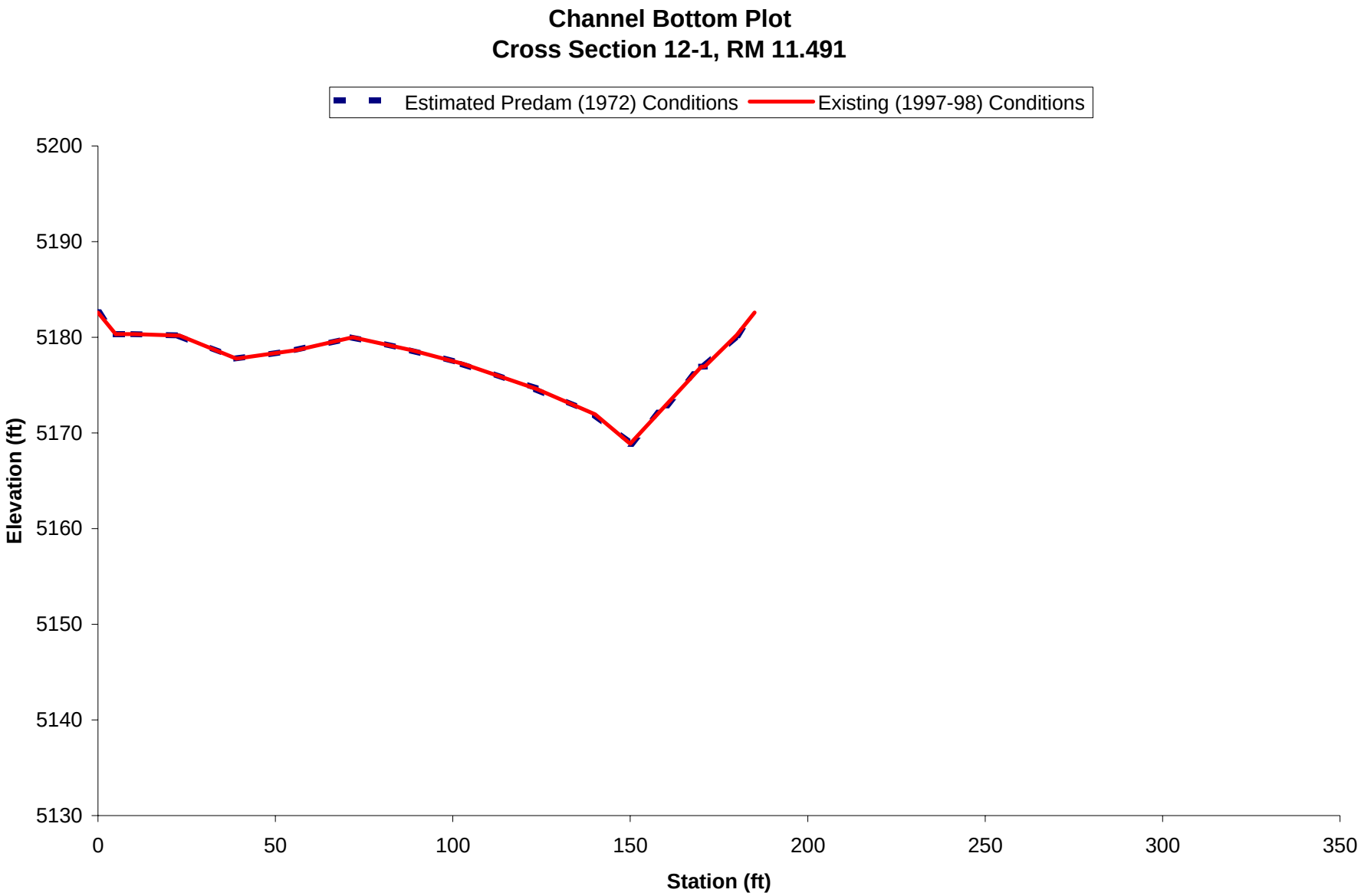

Channel Bottom Plot
Cross Section 10-3, RM 11.935
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

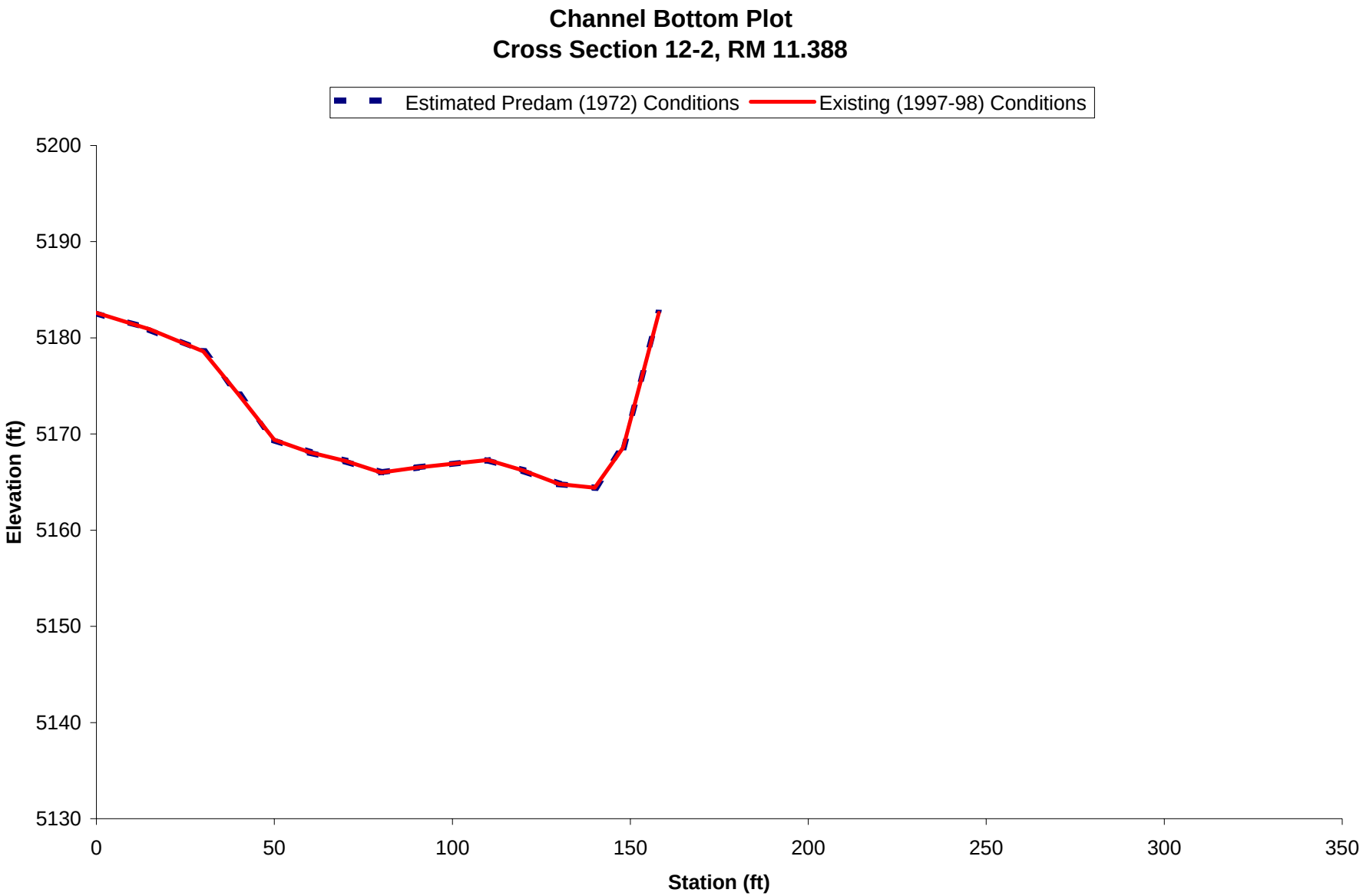

Channel Bottom Plot
Cross Section 11-1, RM 11.786
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

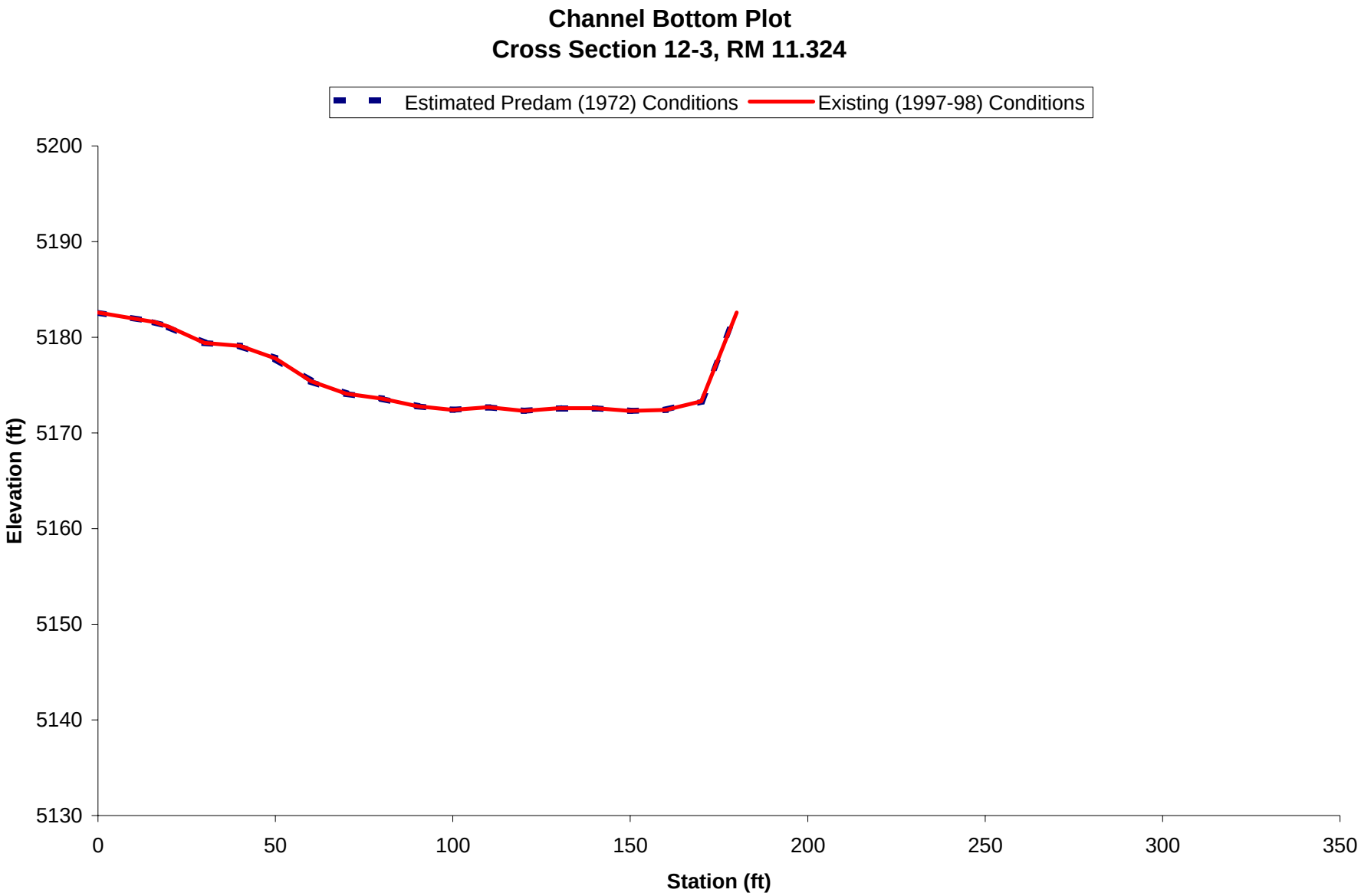

Channel Bottom Plot
Cross Section 11-2, RM 11.709
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

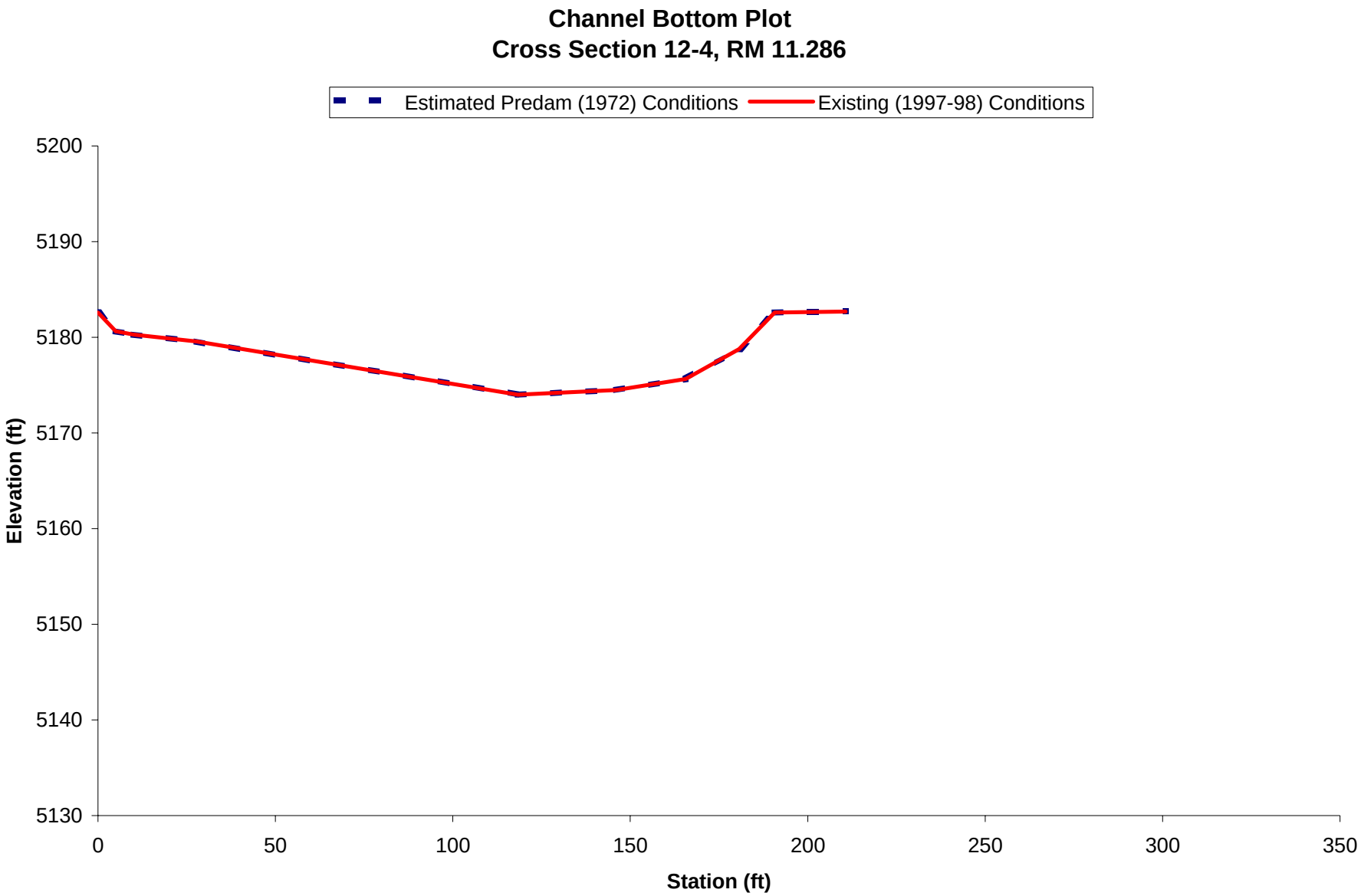

Channel Bottom Plot
Cross Section 11-3, RM 11.636
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

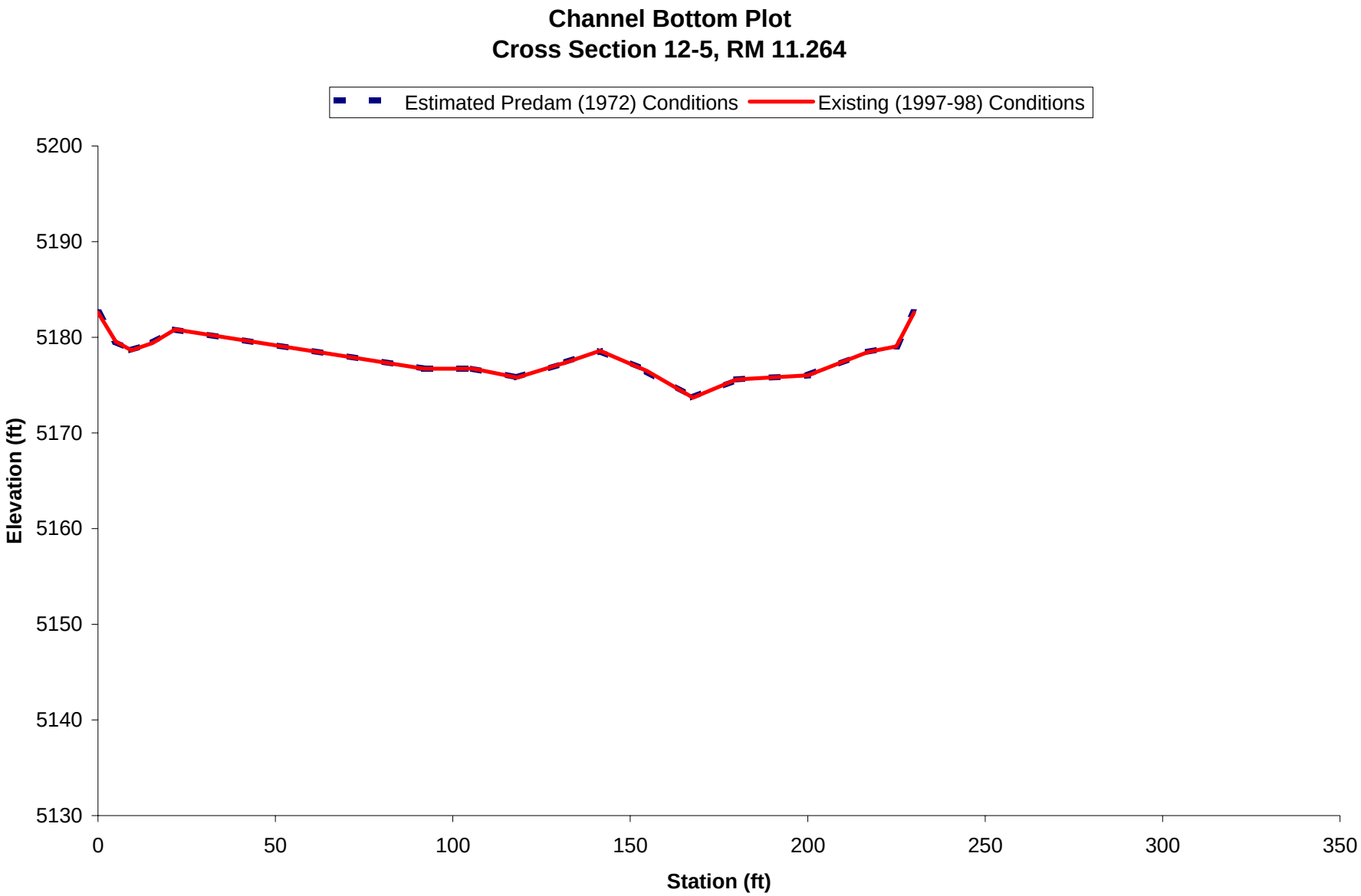

Channel Bottom Plot
Cross Section 11-4, RM 11.577
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

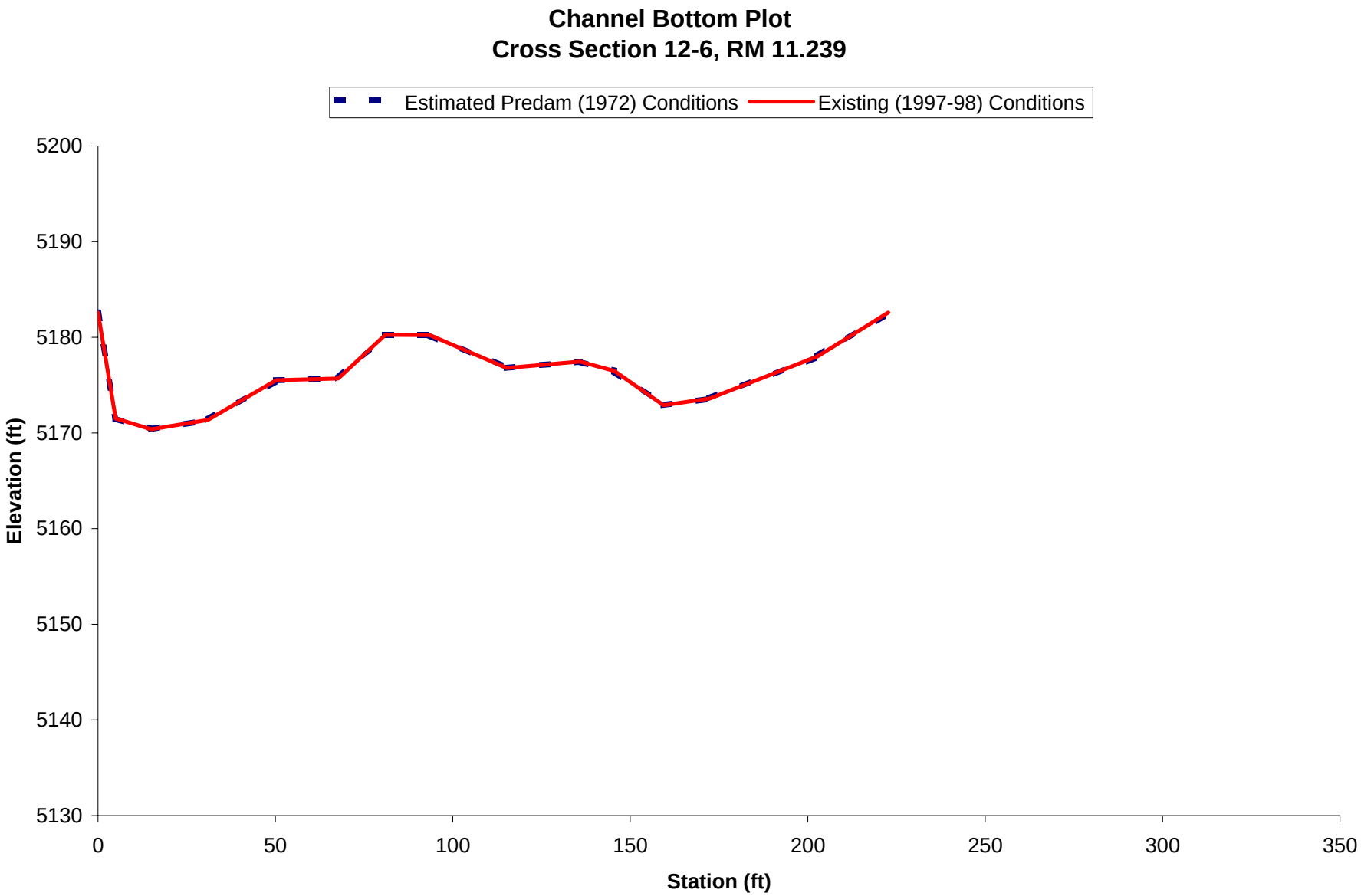

Channel Bottom Plot
Cross Section 12-1, RM 11.491
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

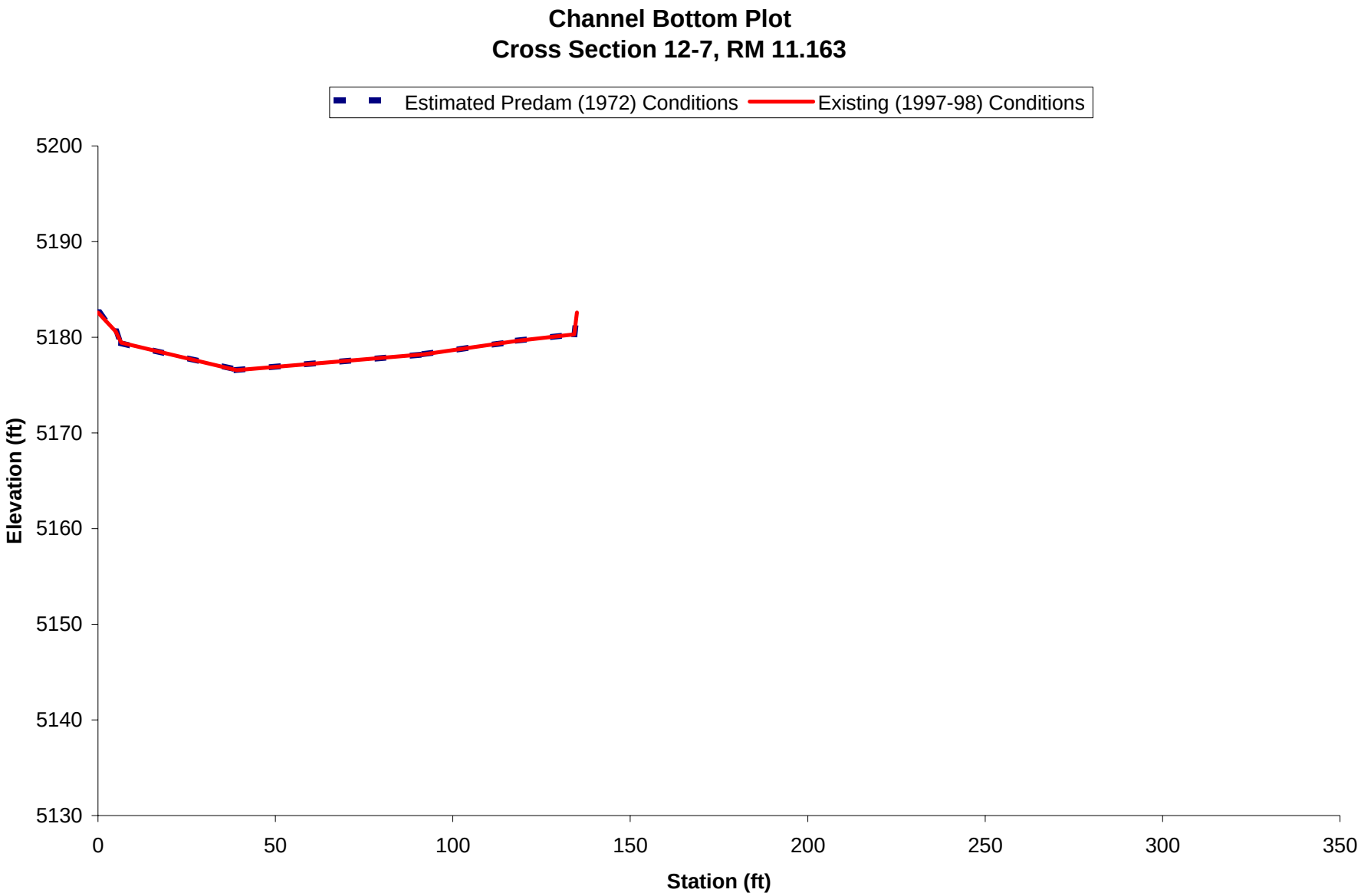

Channel Bottom Plot
Cross Section 12-2, RM 11.388
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

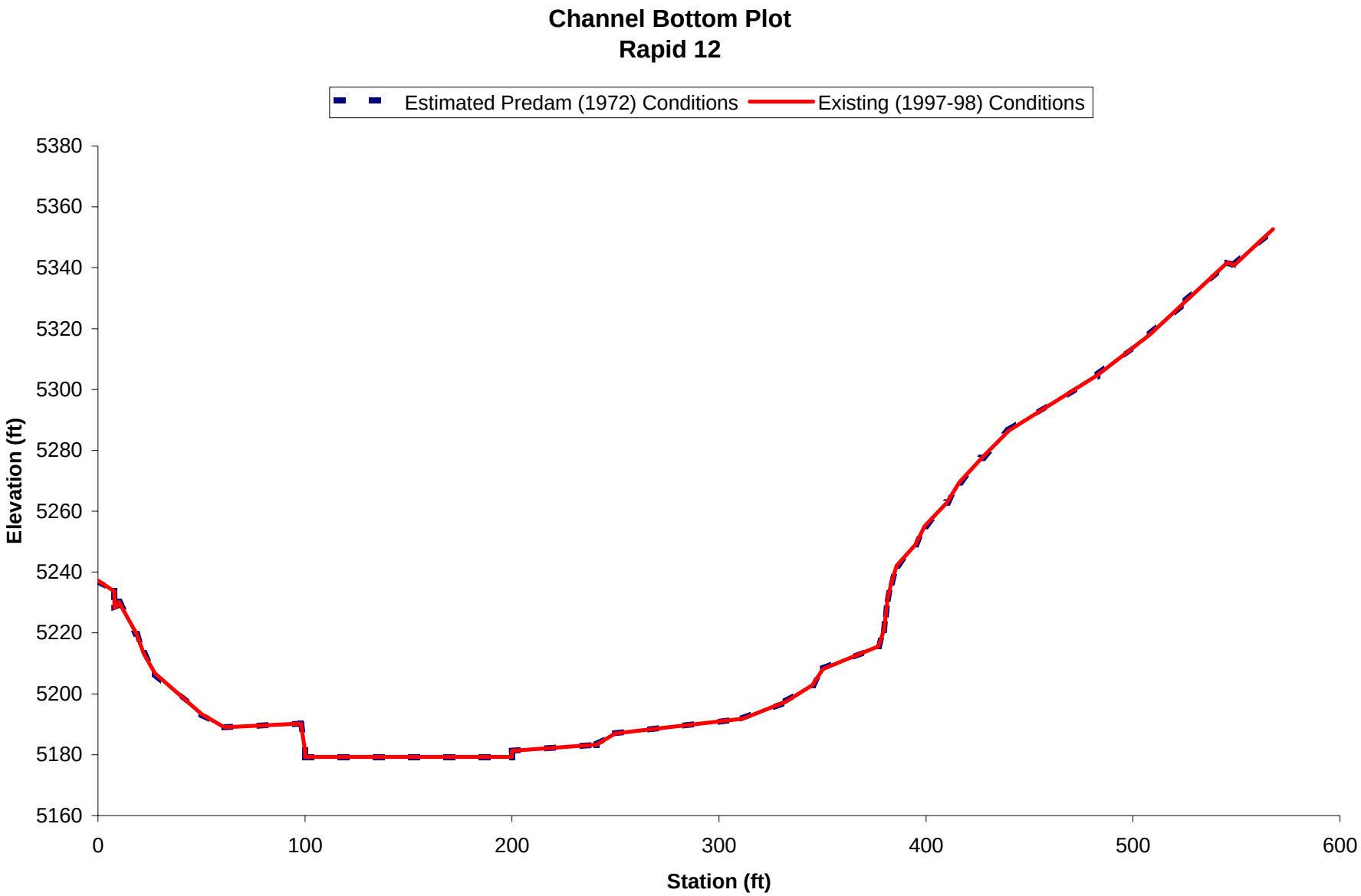

Channel Bottom Plot
Cross Section 12-3, RM 11.324
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

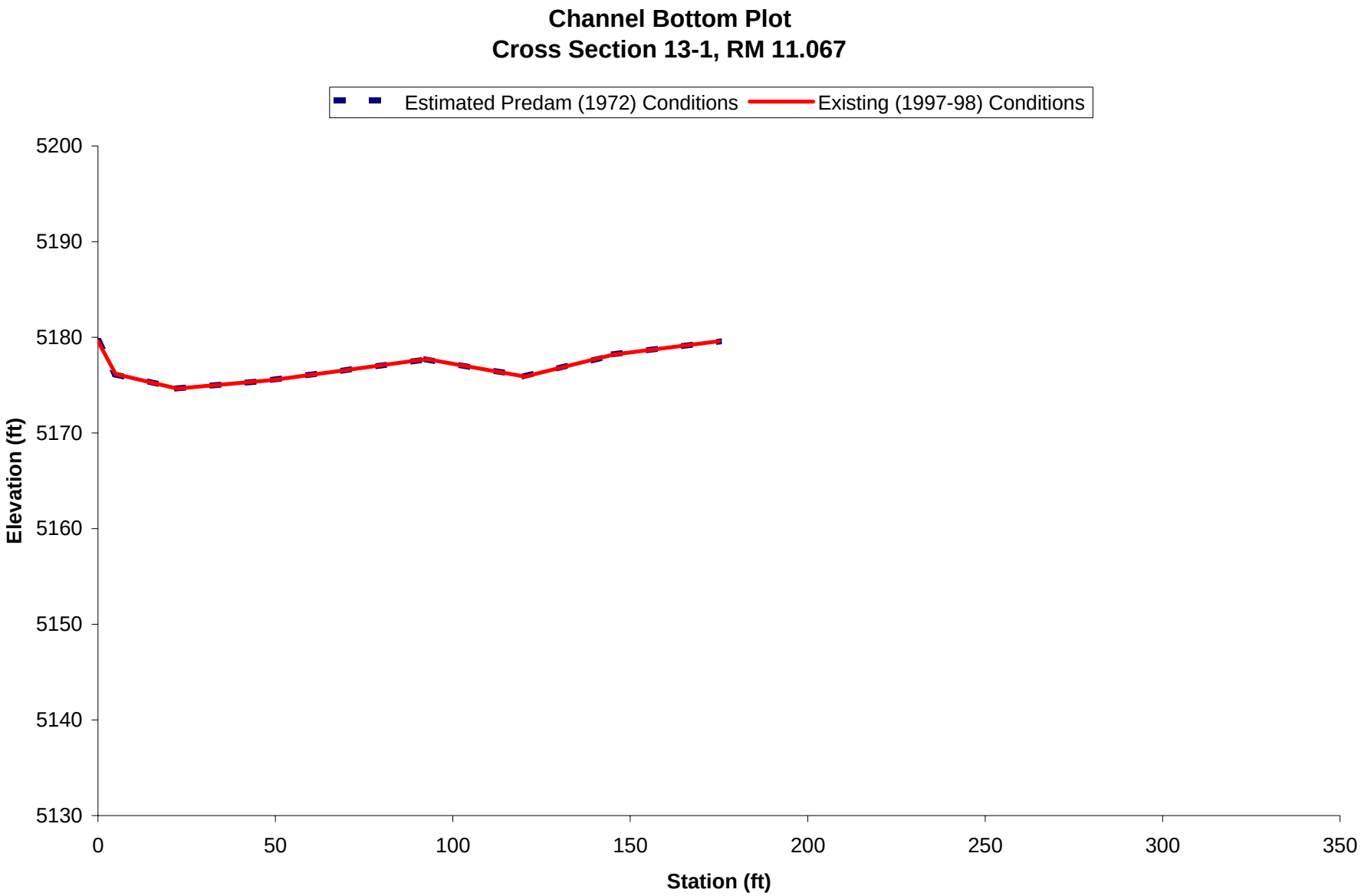

Channel Bottom Plot
Cross Section 12-4, RM 11.286
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

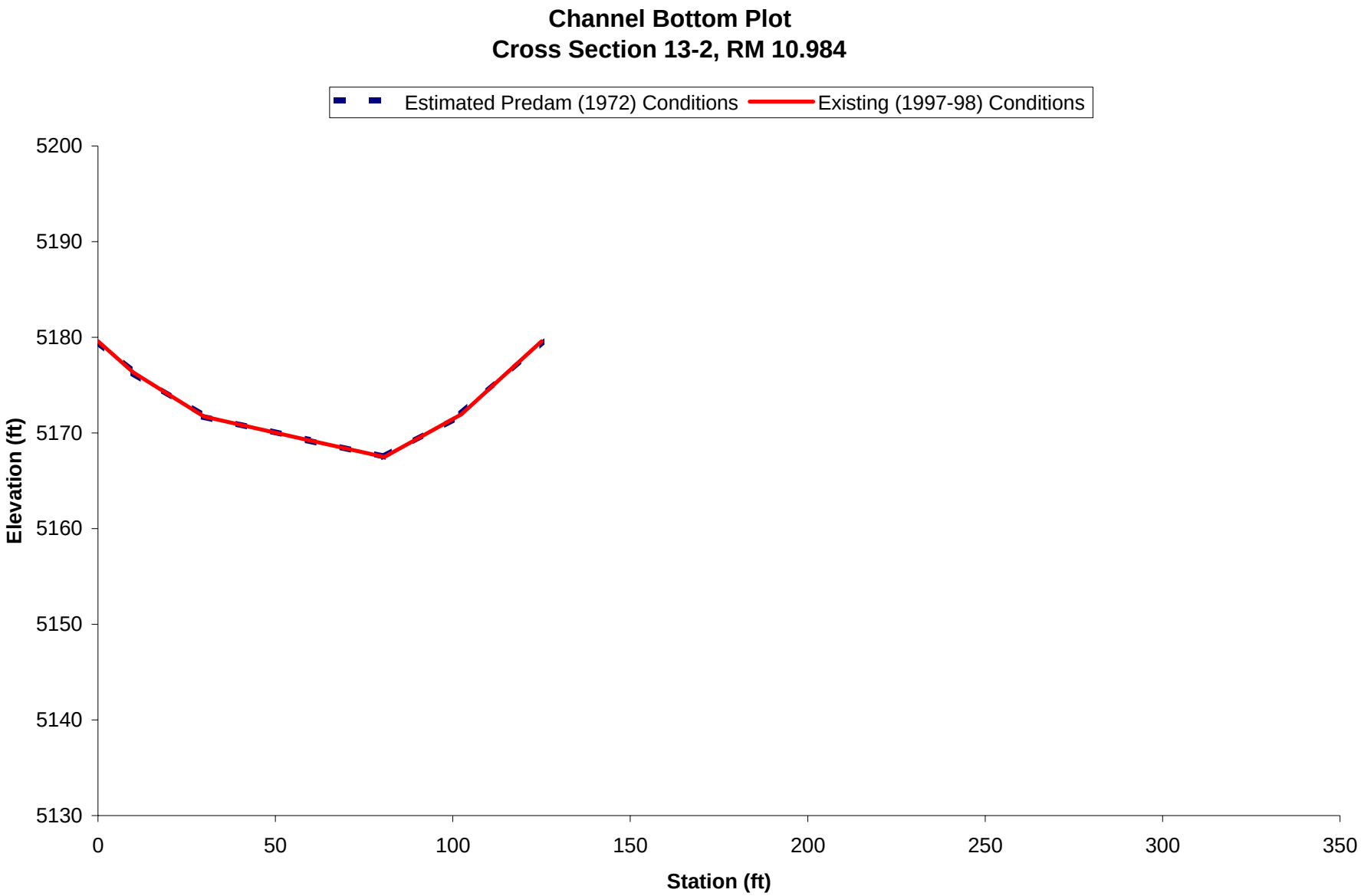

Channel Bottom Plot
Cross Section 12-5, RM 11.264
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

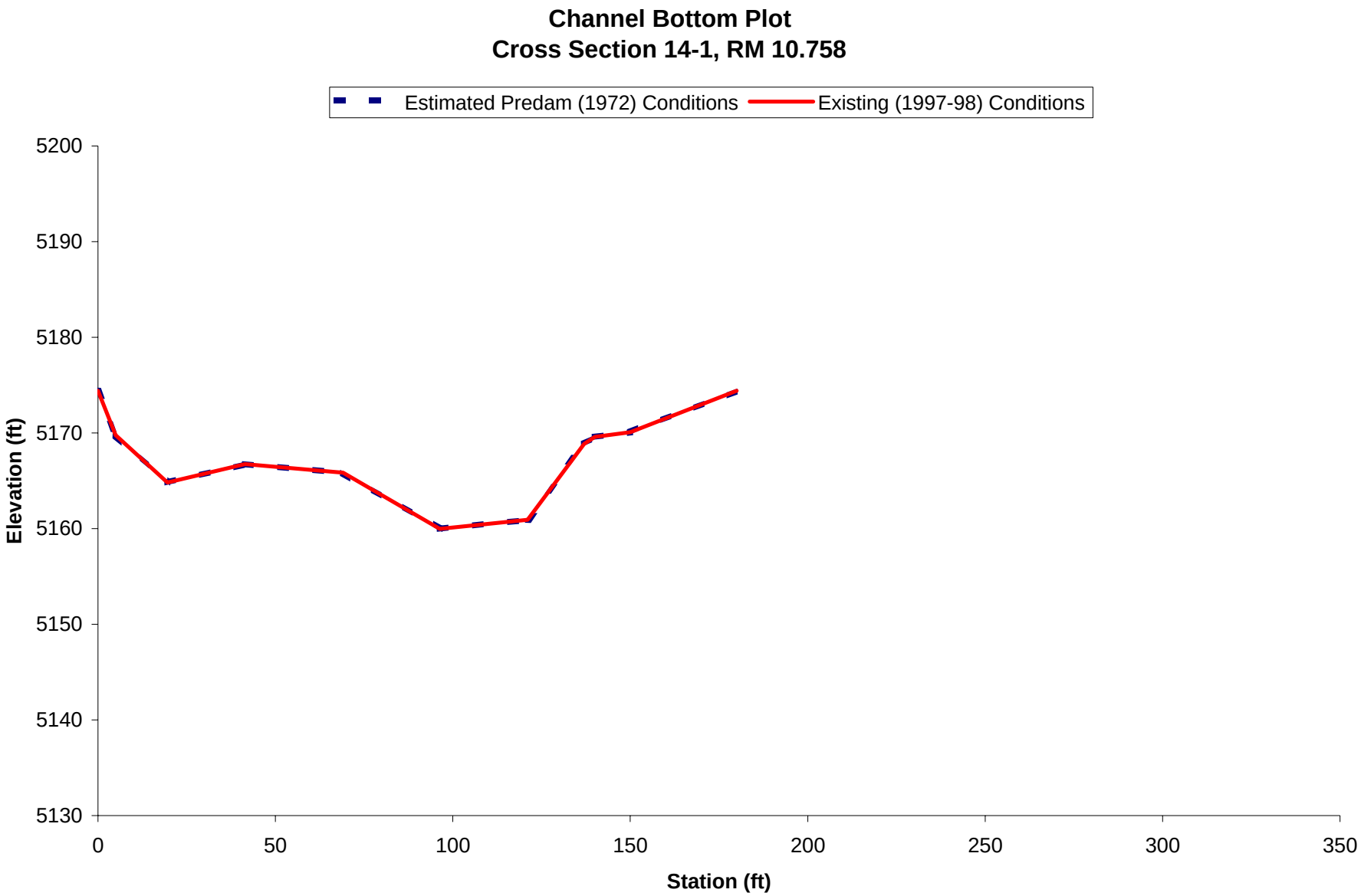

Channel Bottom Plot
Cross Section 12-6, RM 11.239
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

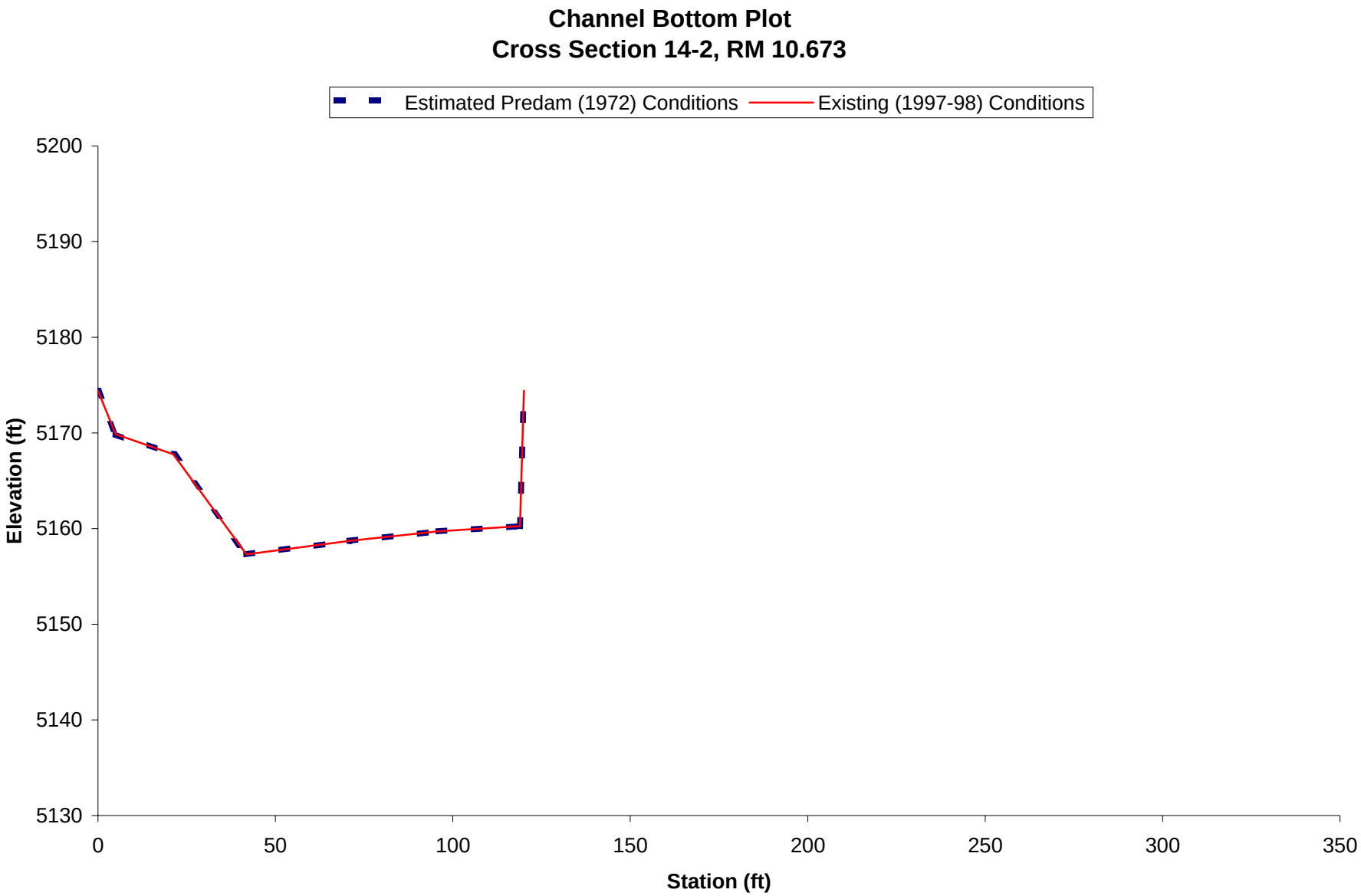

Channel Bottom Plot
Cross Section 12-7, RM 11.163
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

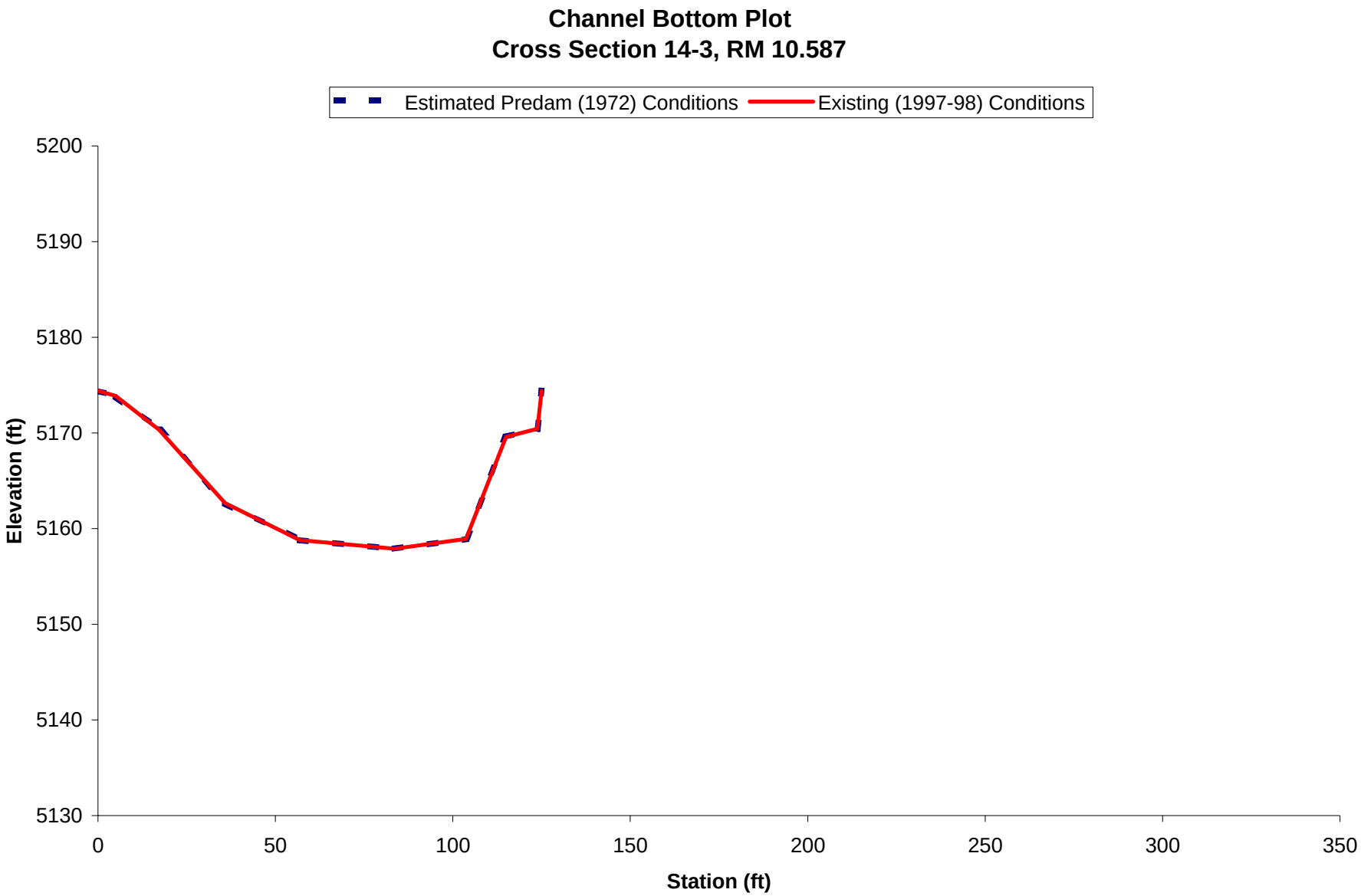

Channel Bottom Plot
Rapid 12
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5380
5360
5340
5320
5300
5280
5260
5240
5220
5200
5180
5160
0
100
200
300
400
500
600
Station (ft)

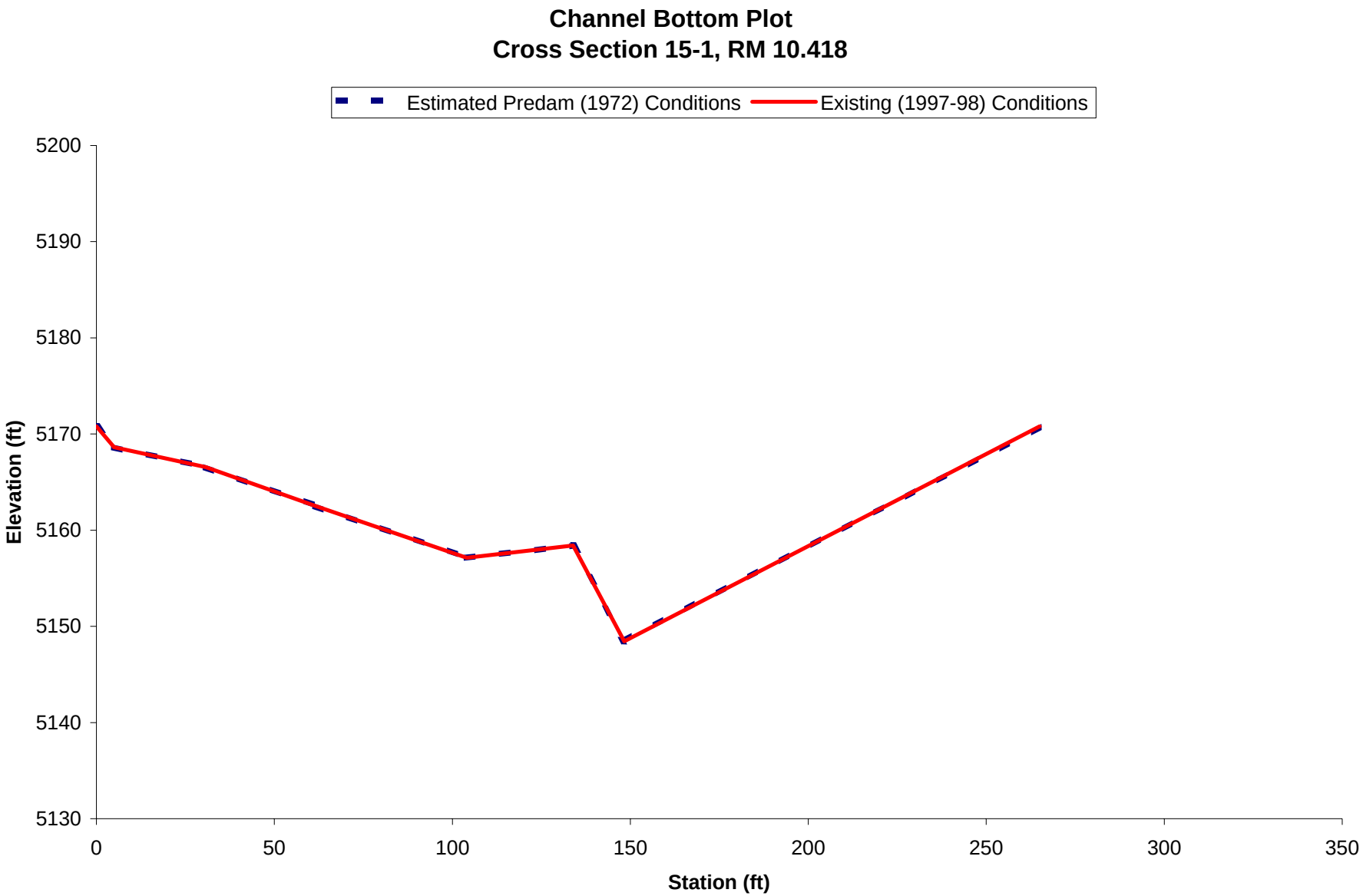

Channel Bottom Plot
Cross Section 13-1, RM 11.067
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

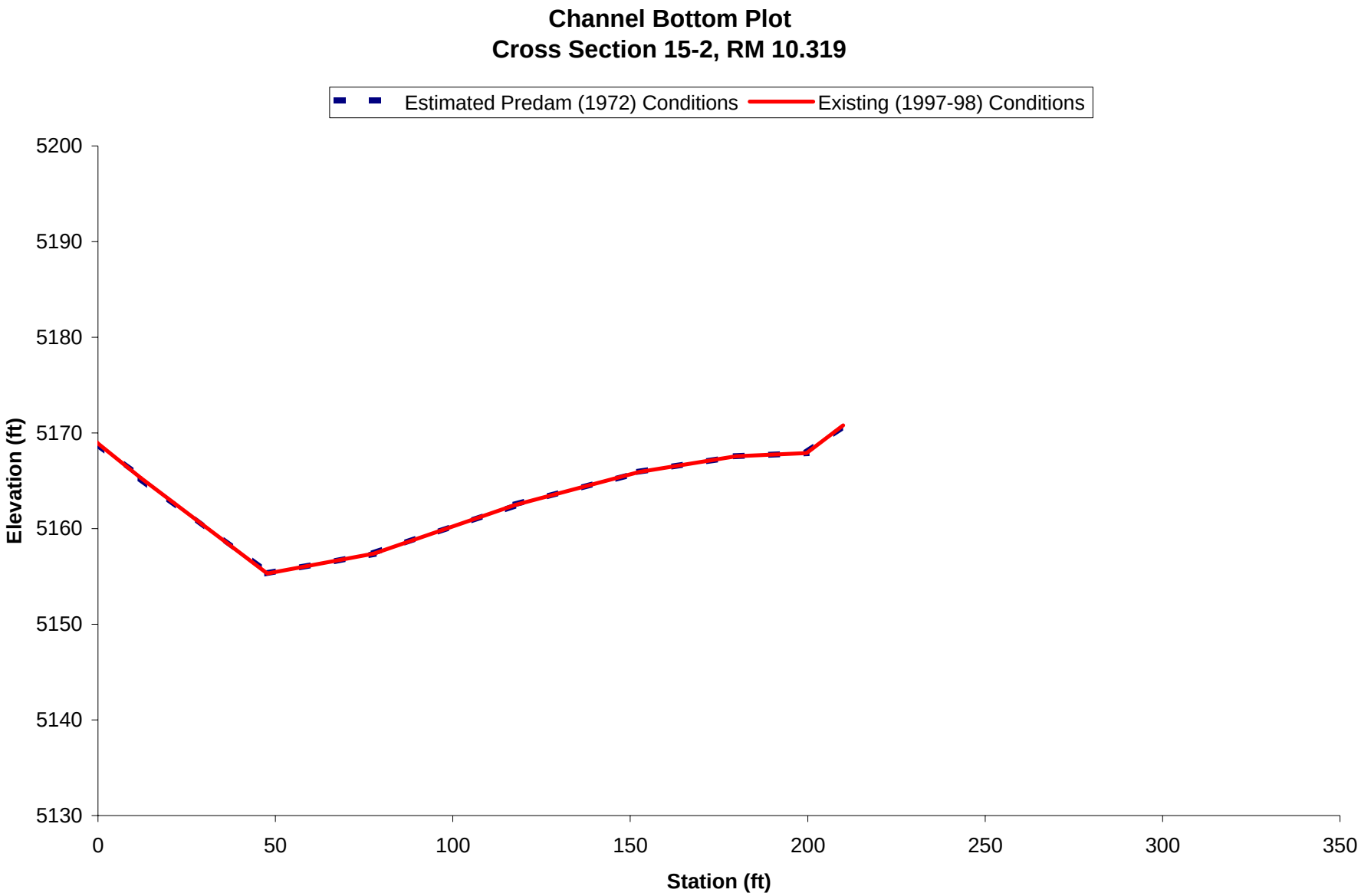

Channel Bottom Plot
Cross Section 13-2, RM 10.984
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

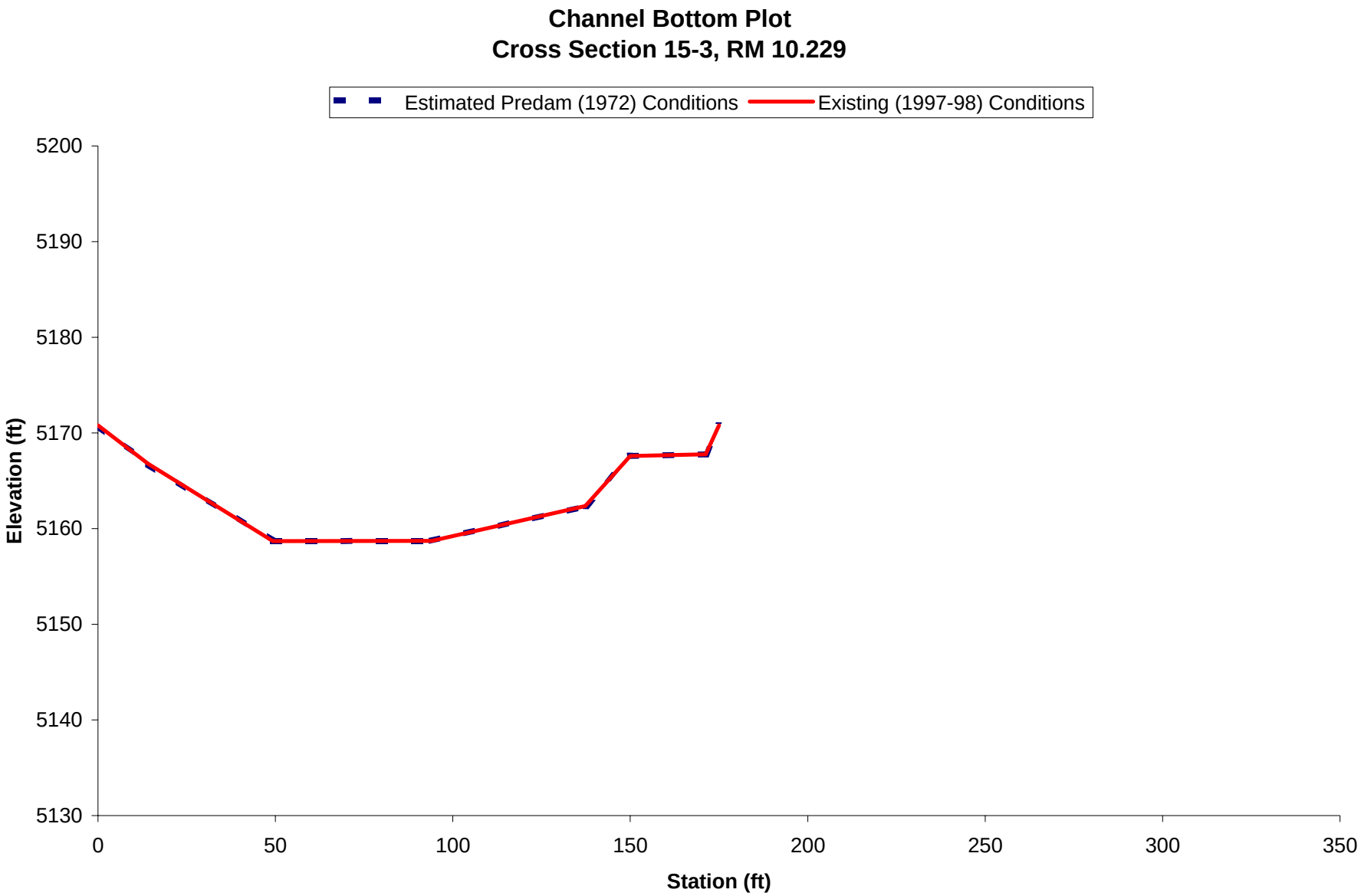

Channel Bottom Plot
Cross Section 14-1, RM 10.758
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

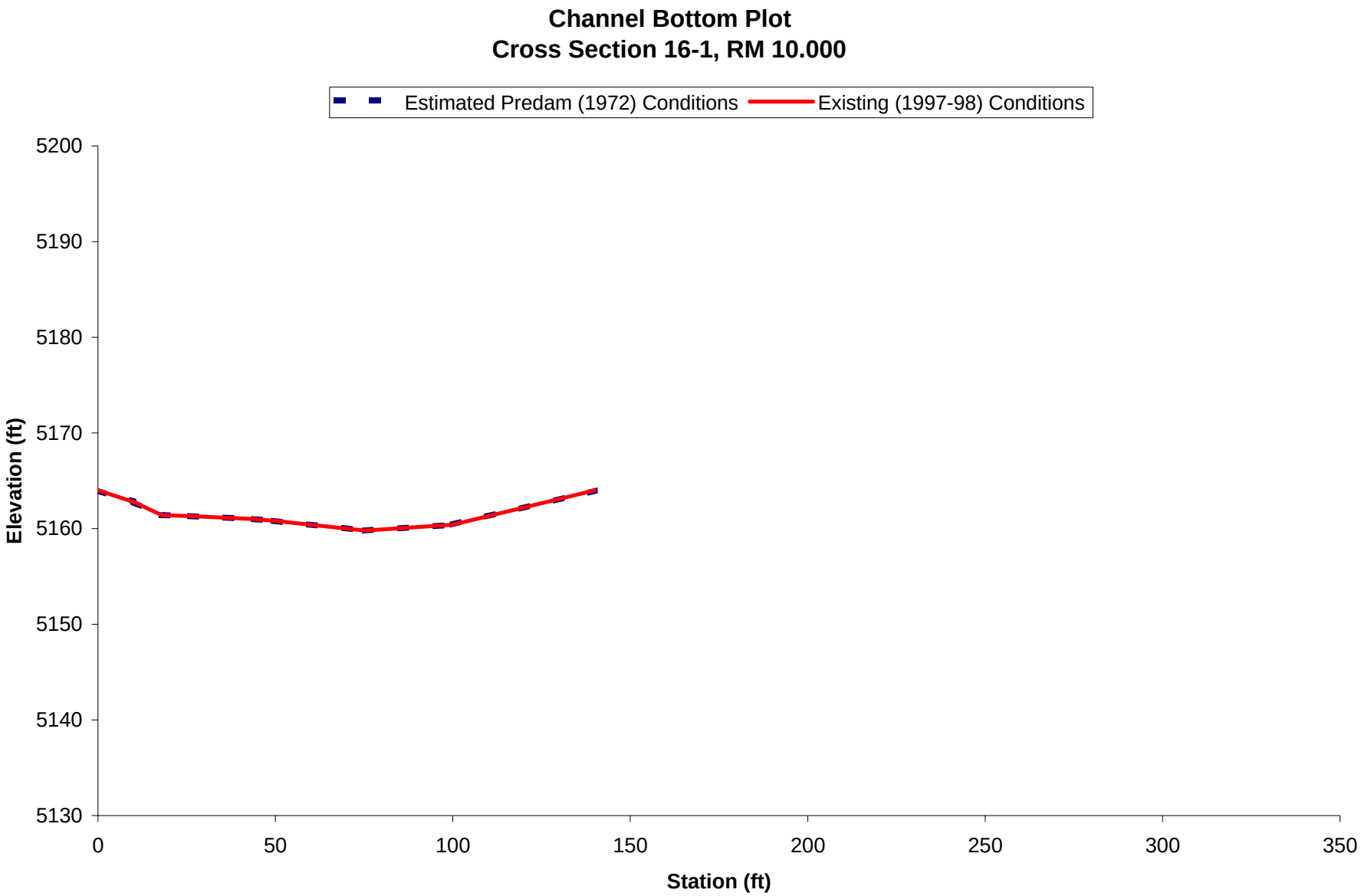

Channel Bottom Plot
Cross Section 14-2, RM 10.673
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

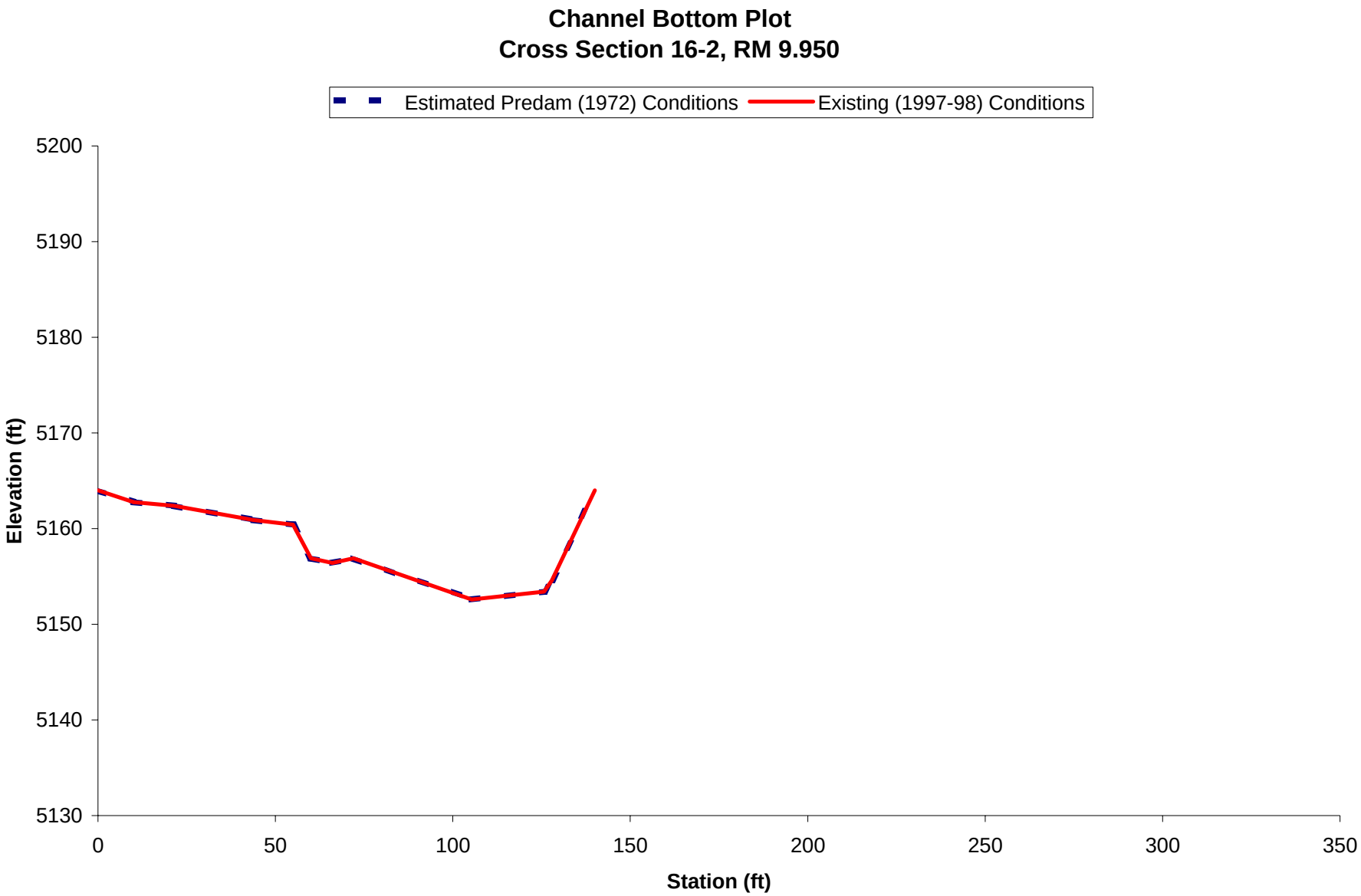

Channel Bottom Plot
Cross Section 14-3, RM 10.587
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

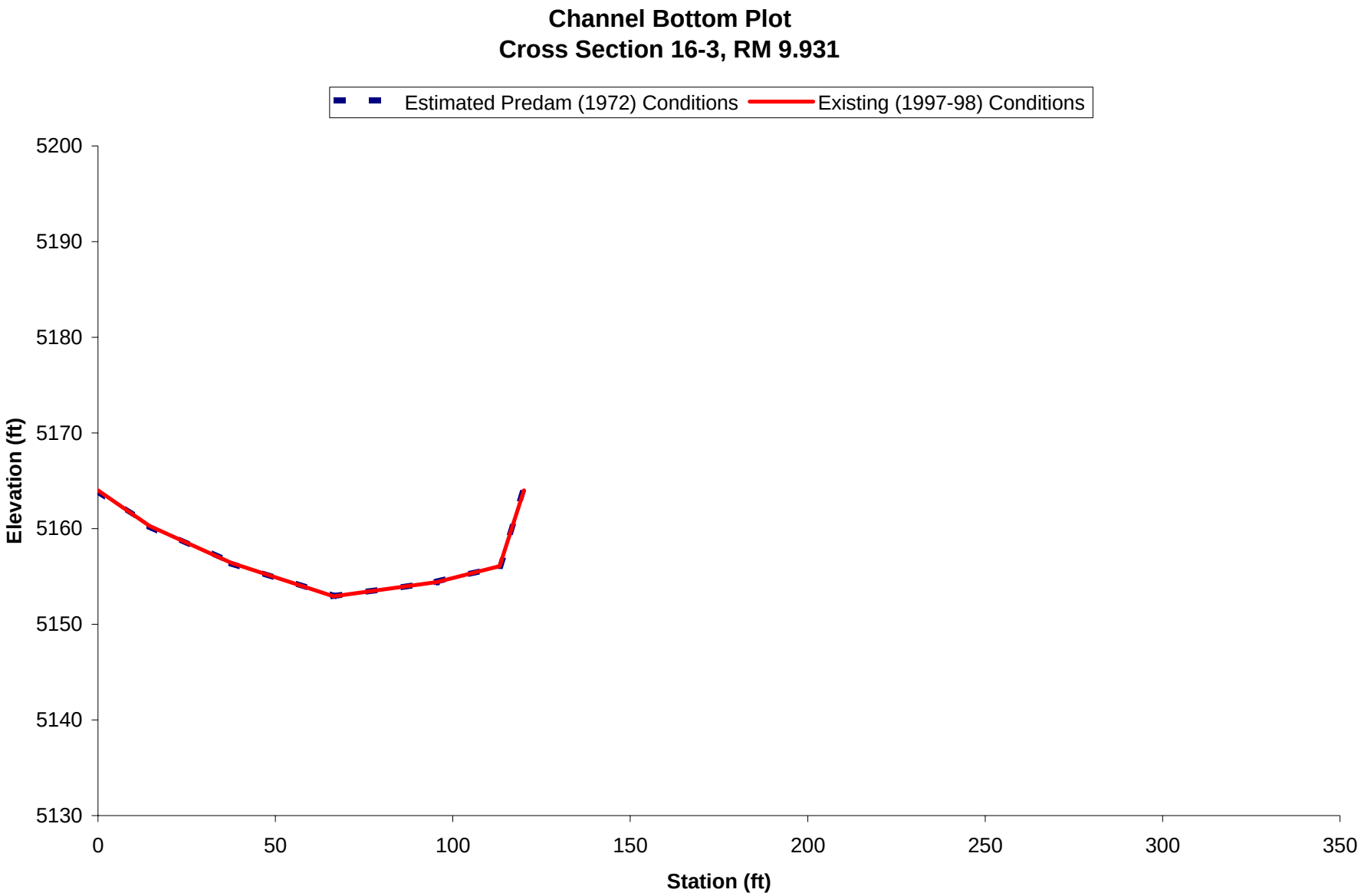

Channel Bottom Plot
Cross Section 15-1, RM 10.418
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

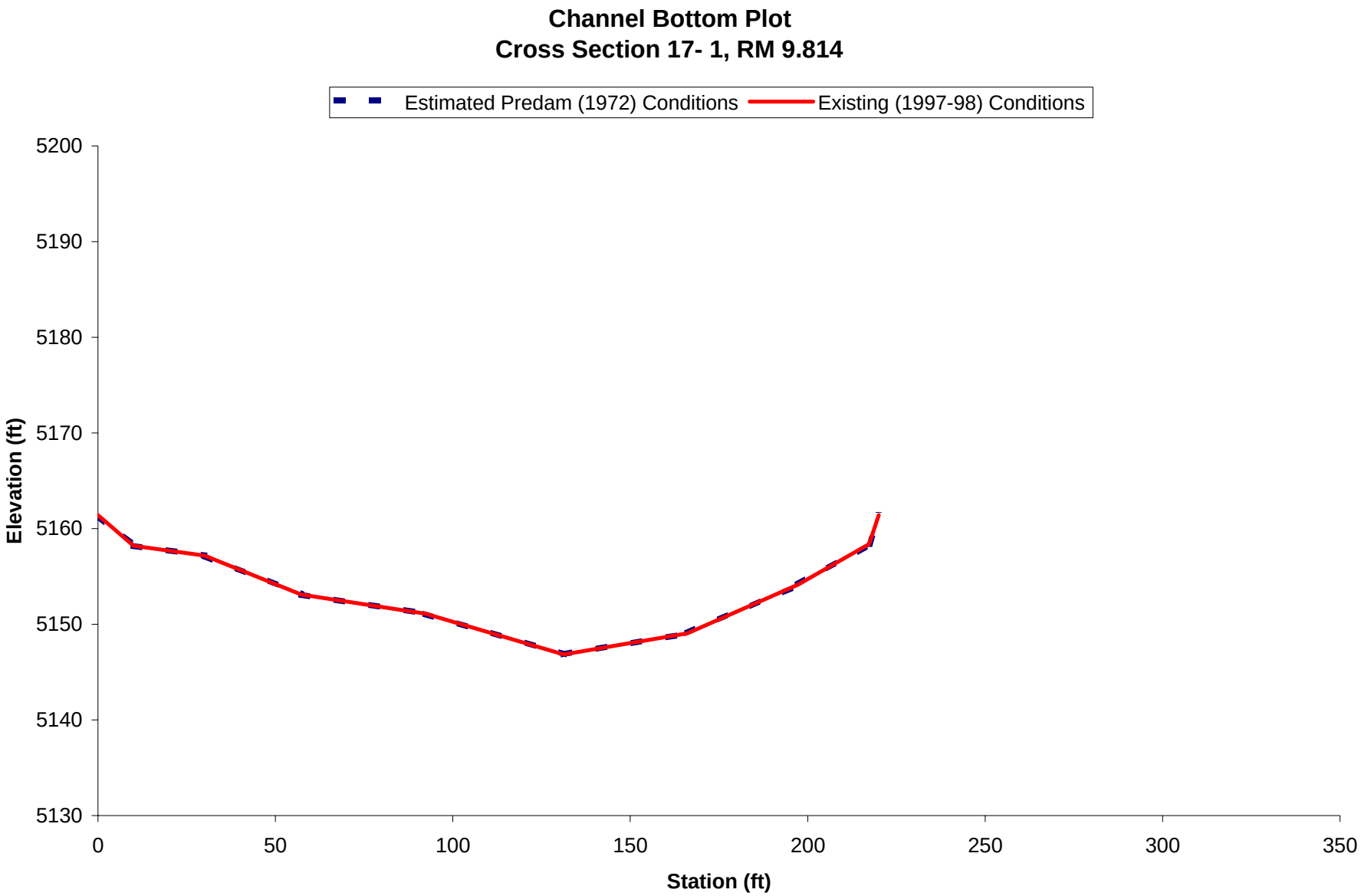

Channel Bottom Plot
Cross Section 15-2, RM 10.319
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

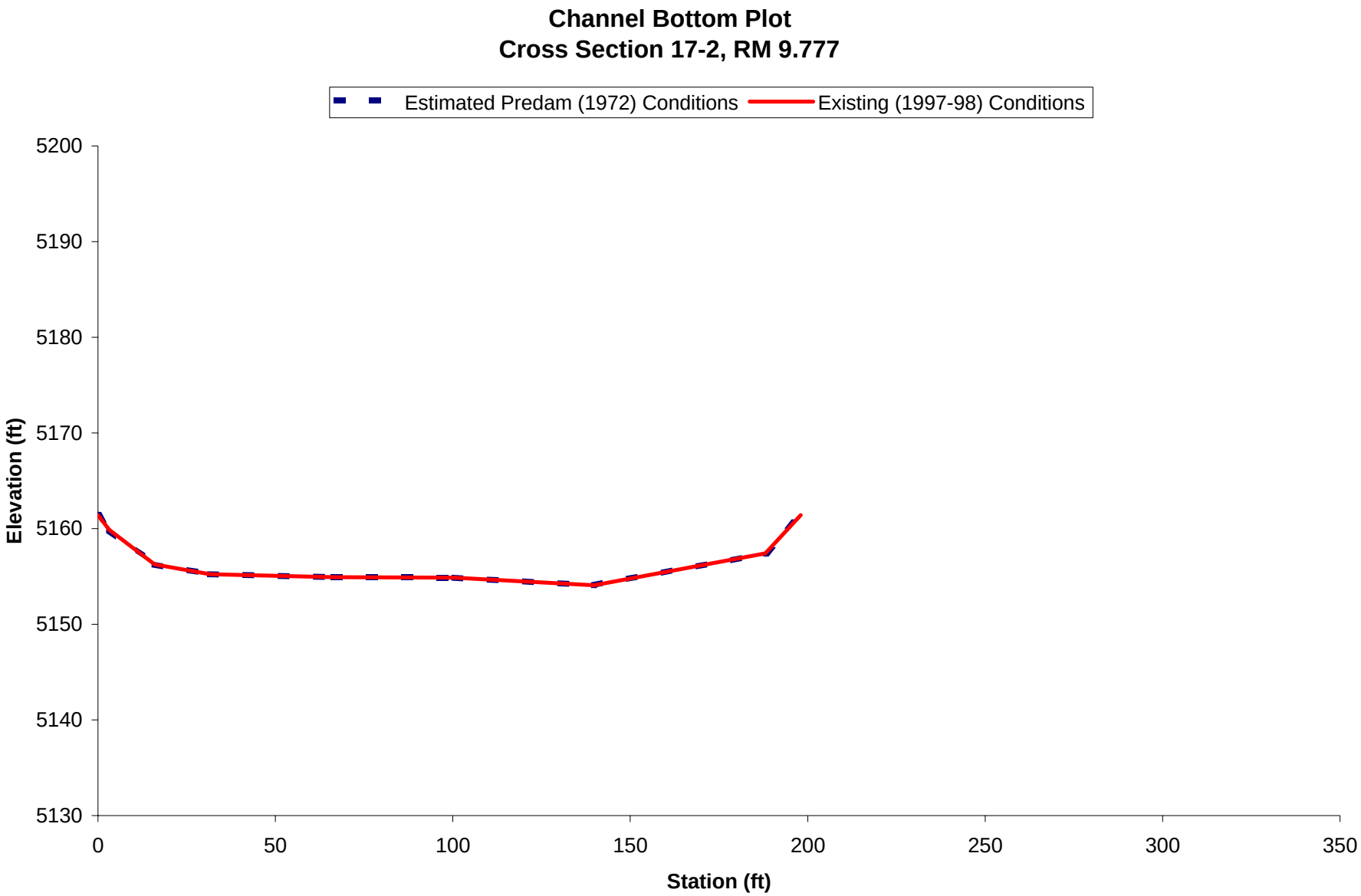

Channel Bottom Plot
Cross Section 15-3, RM 10.229
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

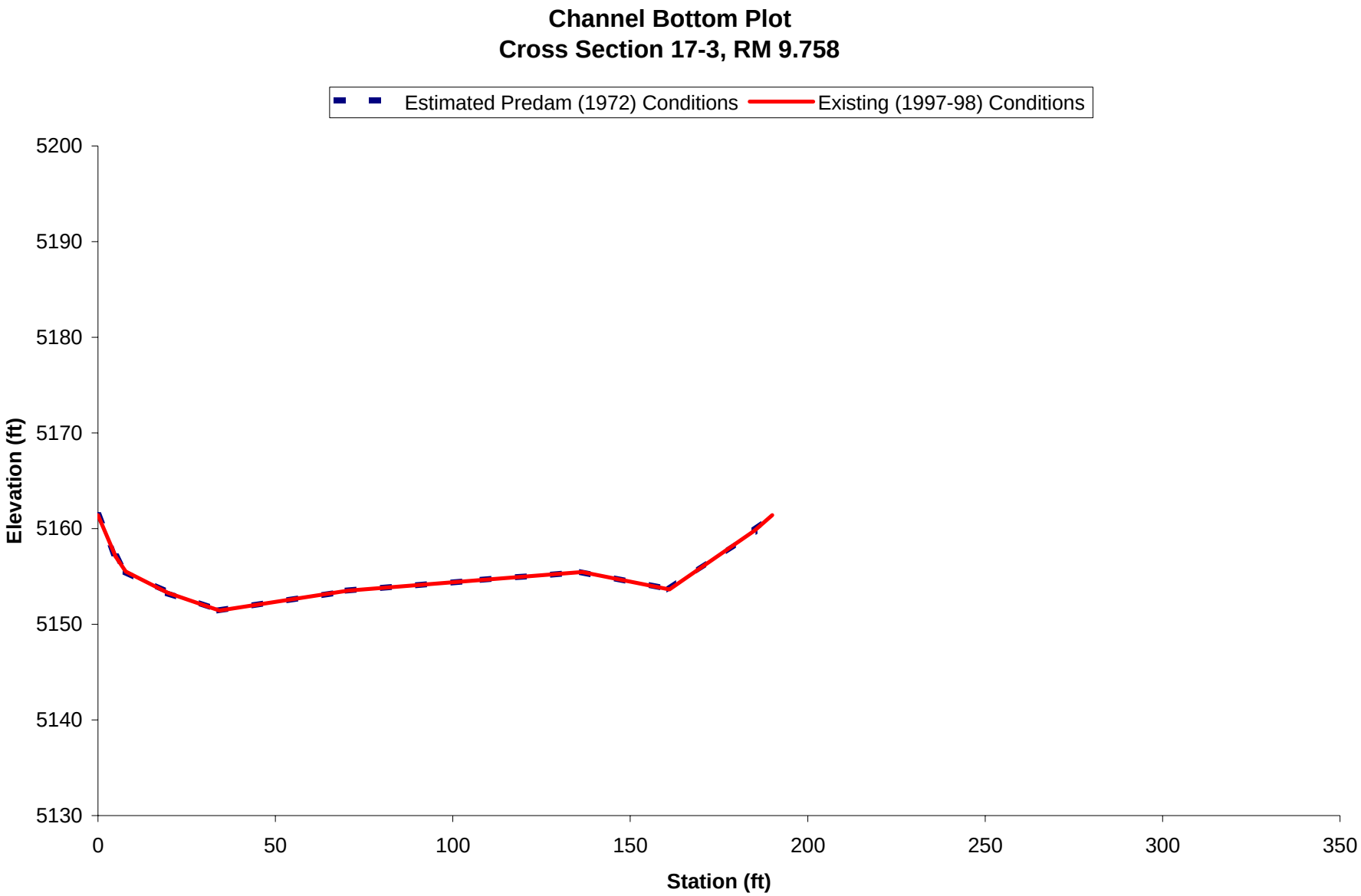

Channel Bottom Plot
Cross Section 16-1, RM 10.000
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

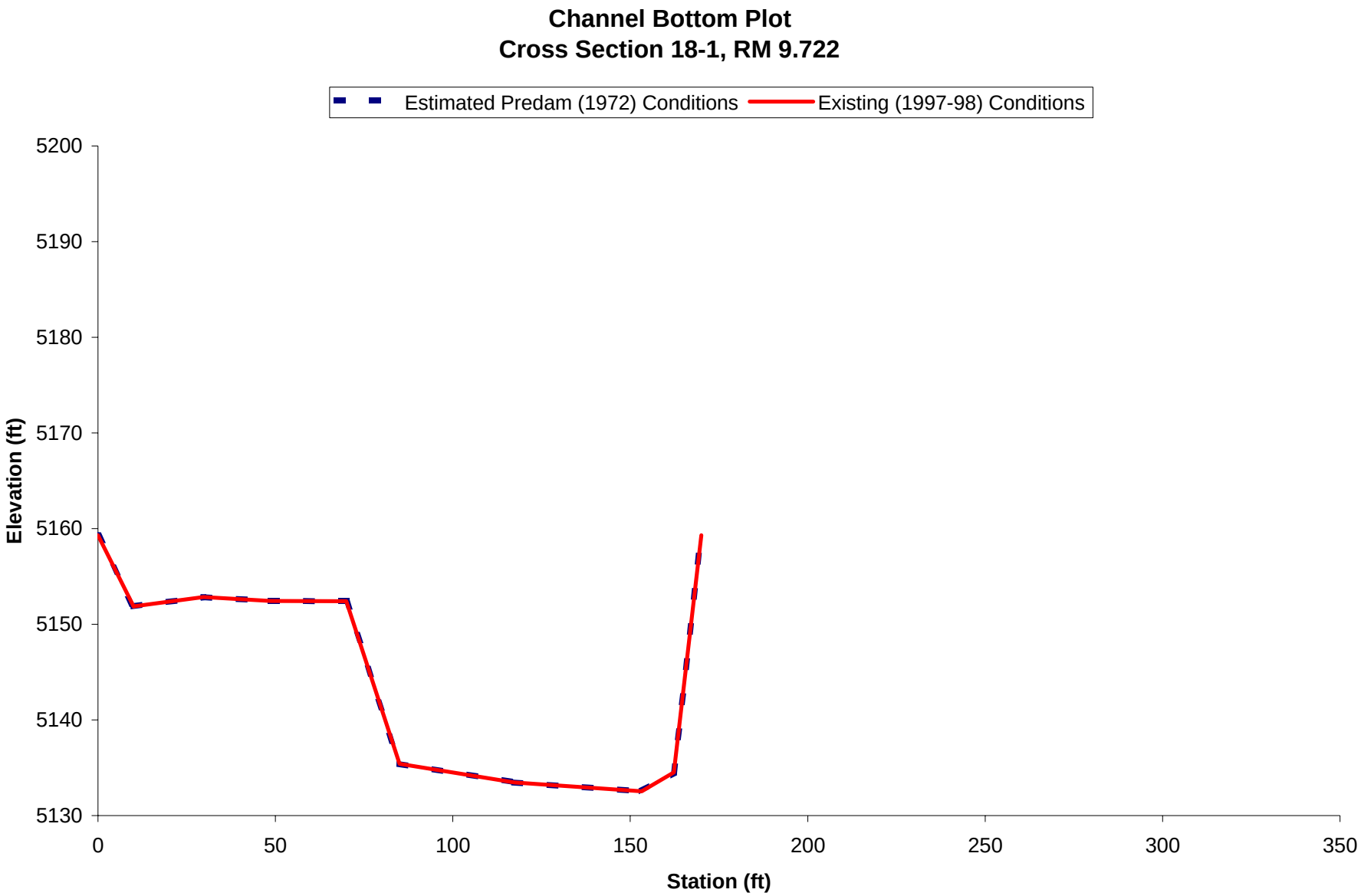

Channel Bottom Plot
Cross Section 16-2, RM 9.950
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

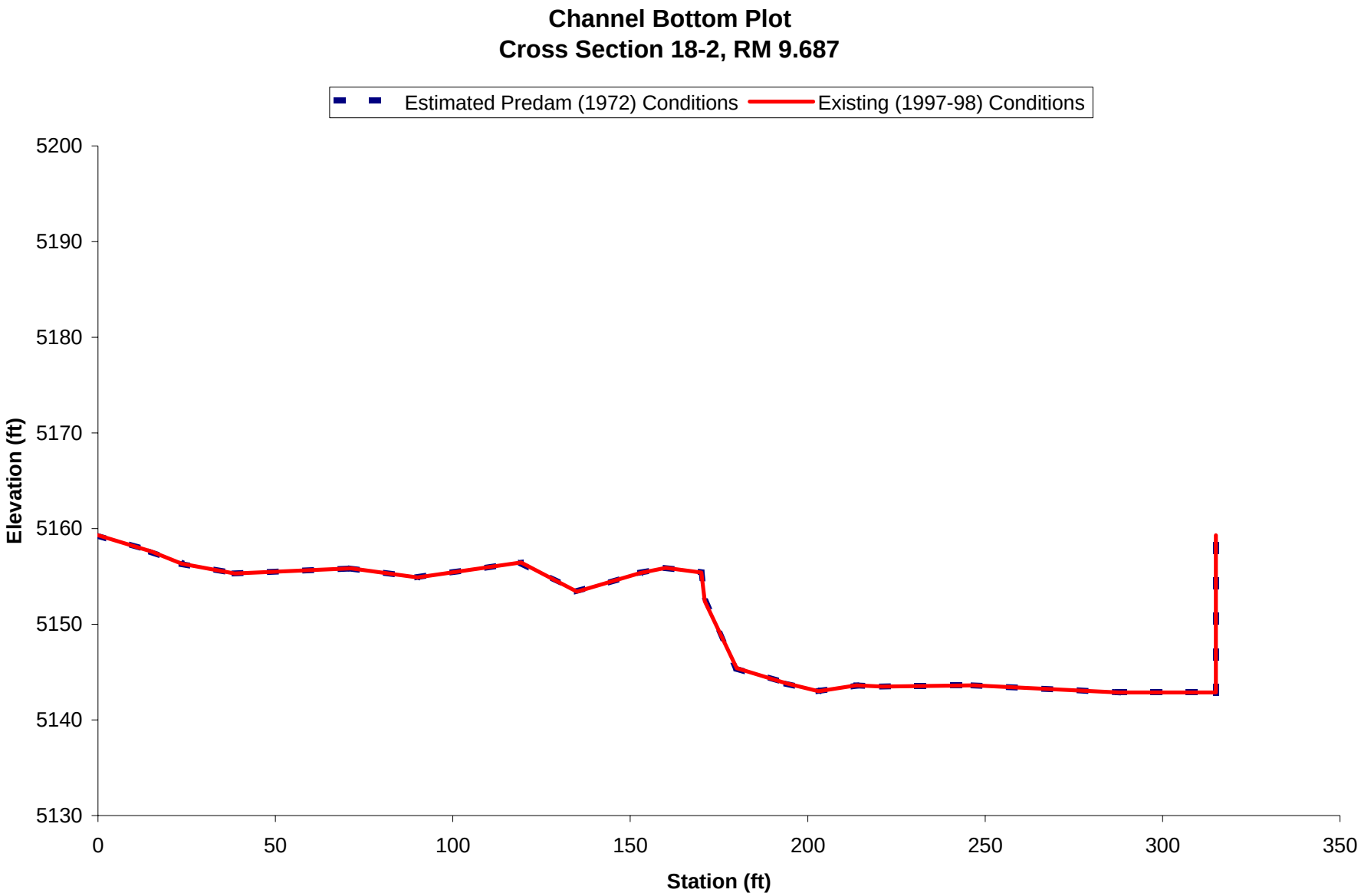

Channel Bottom Plot
Cross Section 16-3, RM 9.931
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

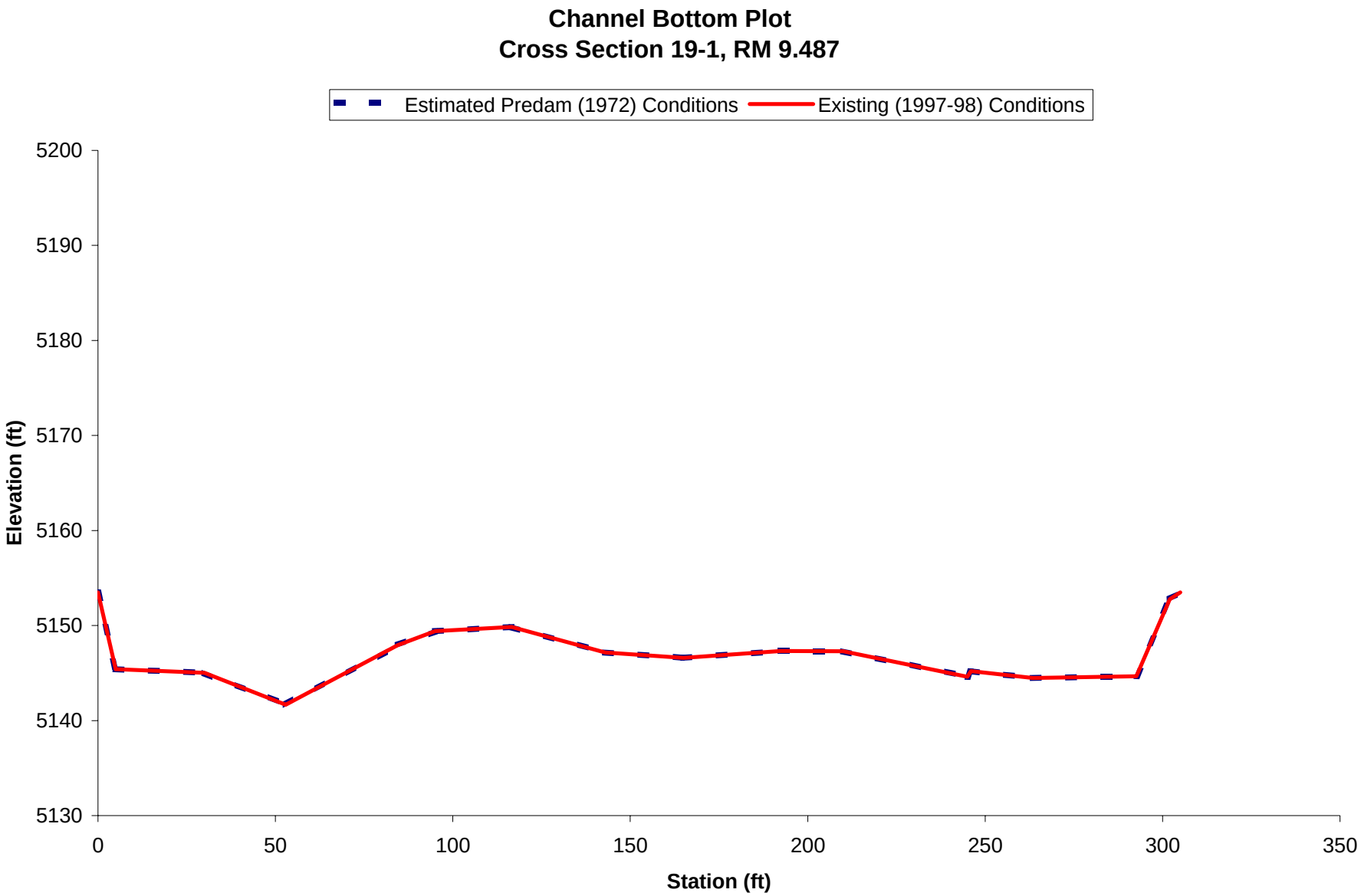

Channel Bottom Plot
Cross Section 17- 1, RM 9.814
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

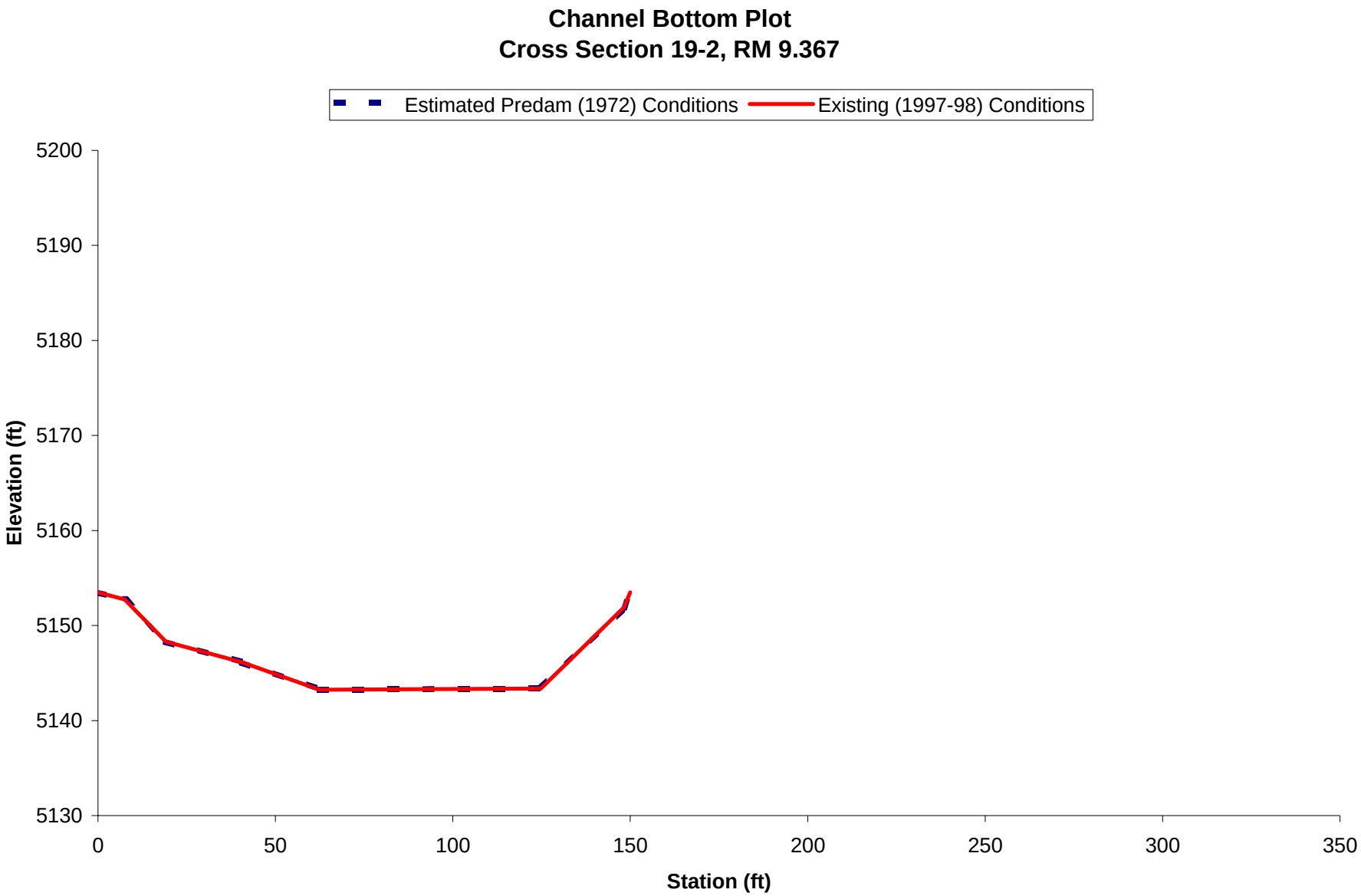

Channel Bottom Plot
Cross Section 17-2, RM 9.777
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

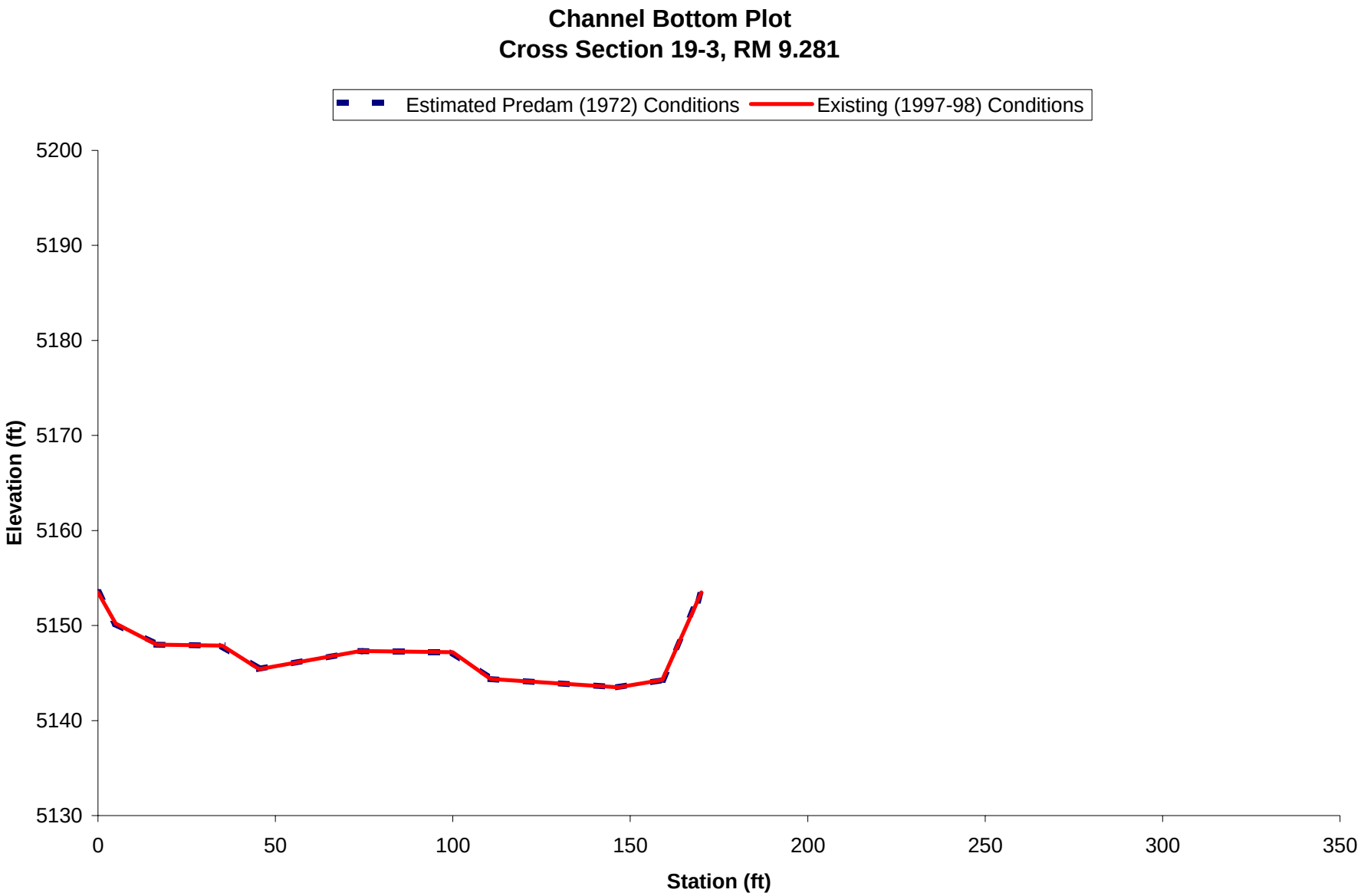

Channel Bottom Plot
Cross Section 17-3, RM 9.758
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

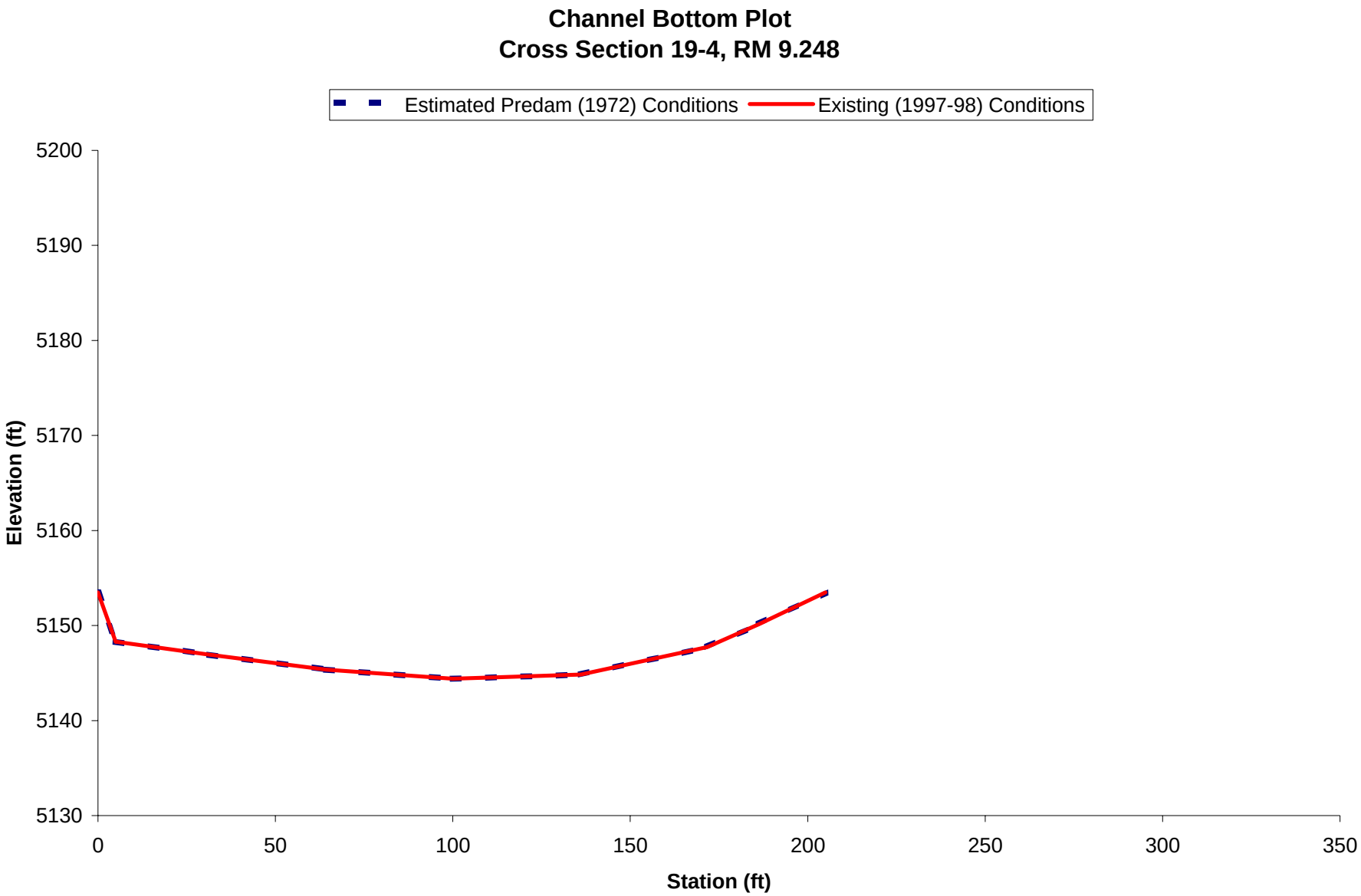

Channel Bottom Plot
Cross Section 18-1, RM 9.722
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

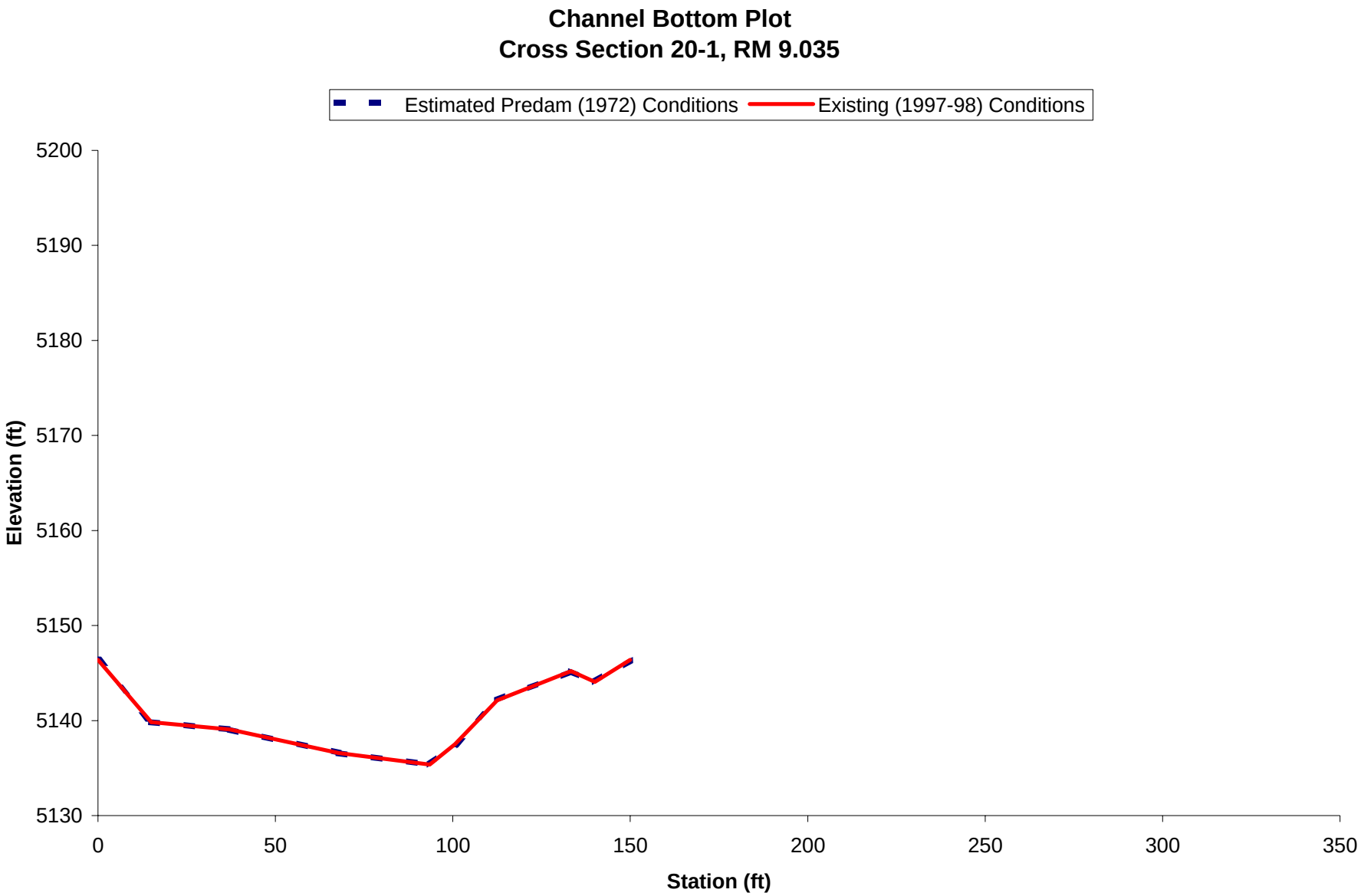

Channel Bottom Plot
Cross Section 18-2, RM 9.687
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

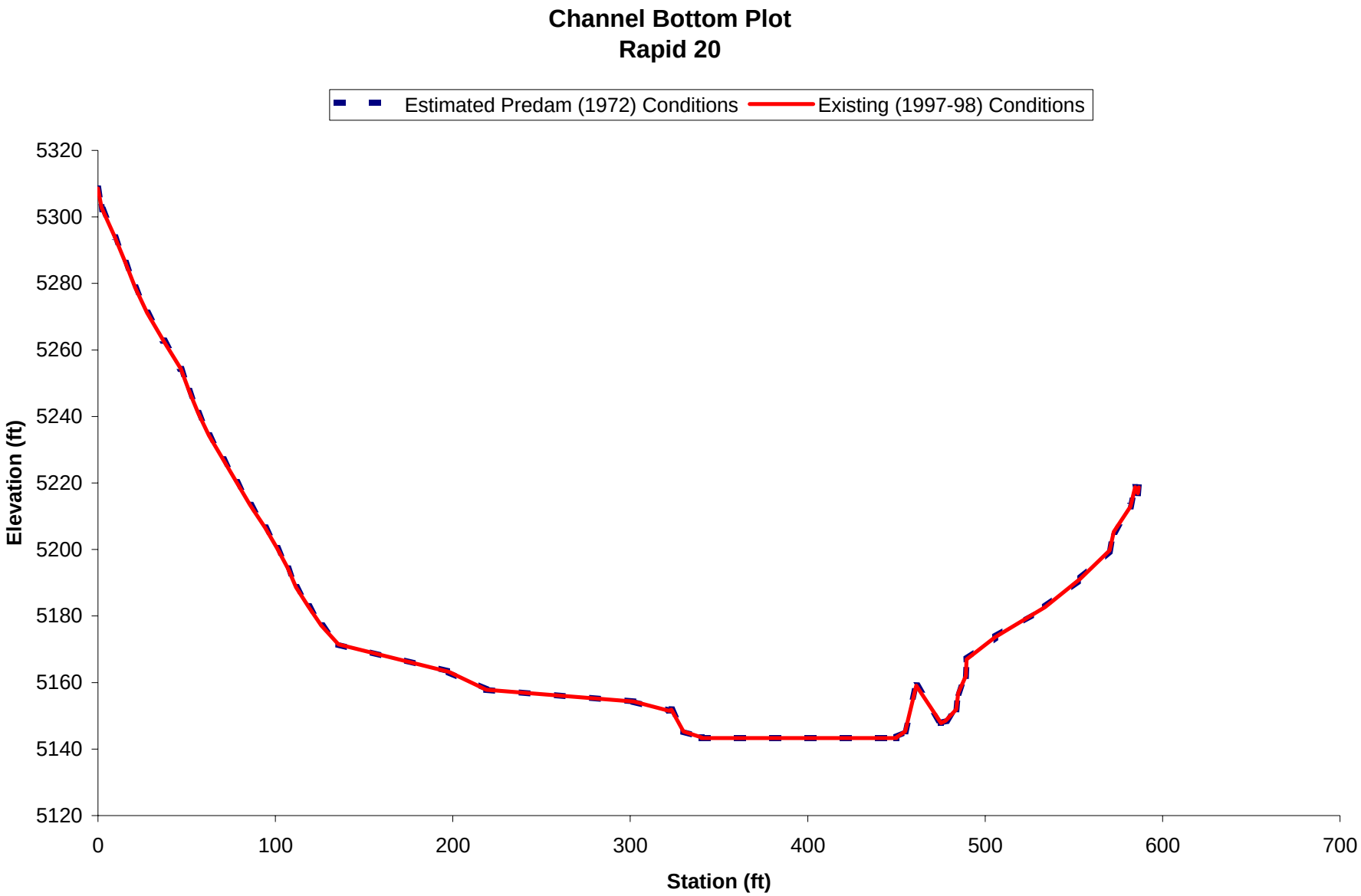

Channel Bottom Plot
Cross Section 19-1, RM 9.487
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

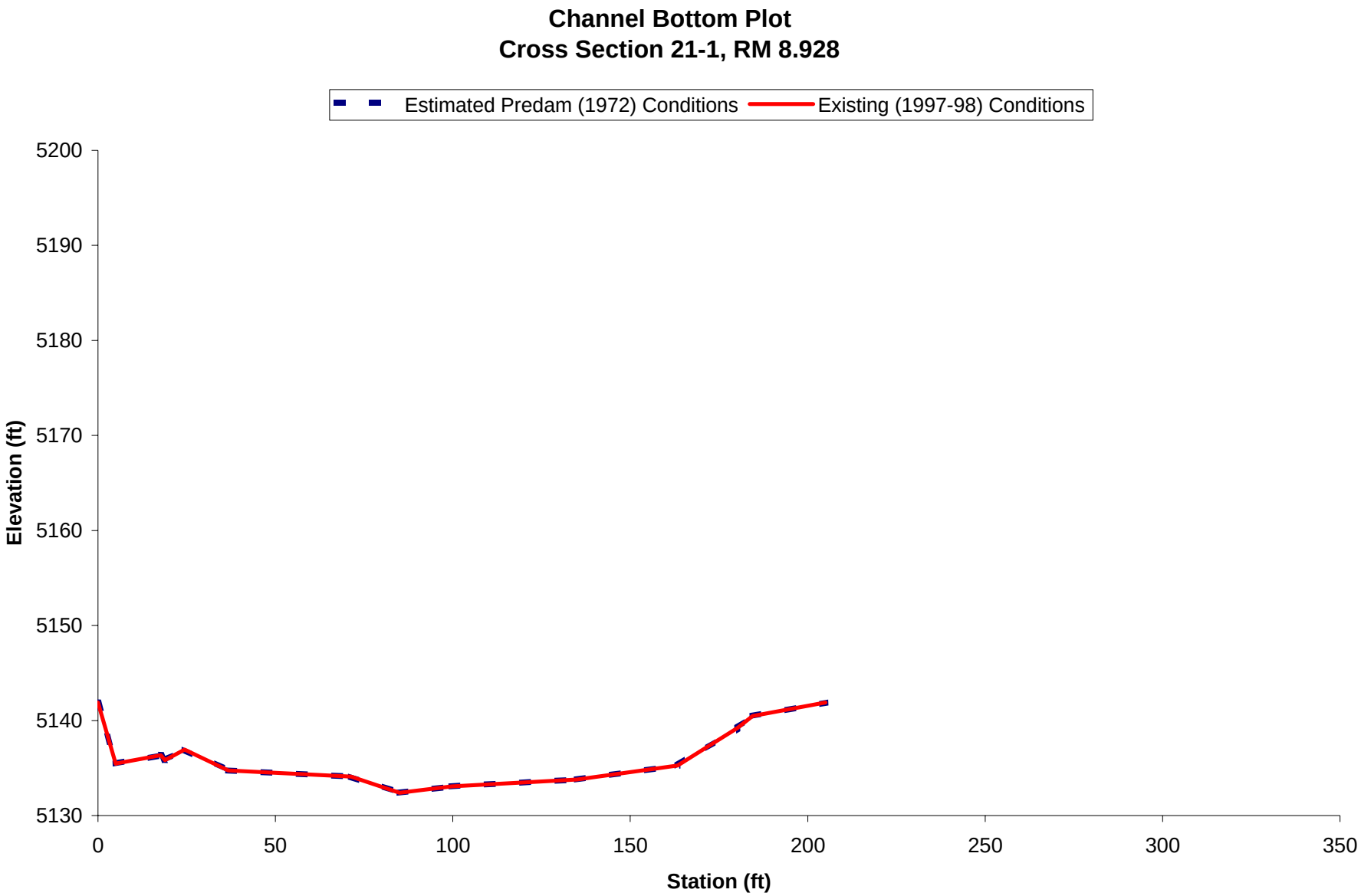

Channel Bottom Plot
Cross Section 19-2, RM 9.367
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

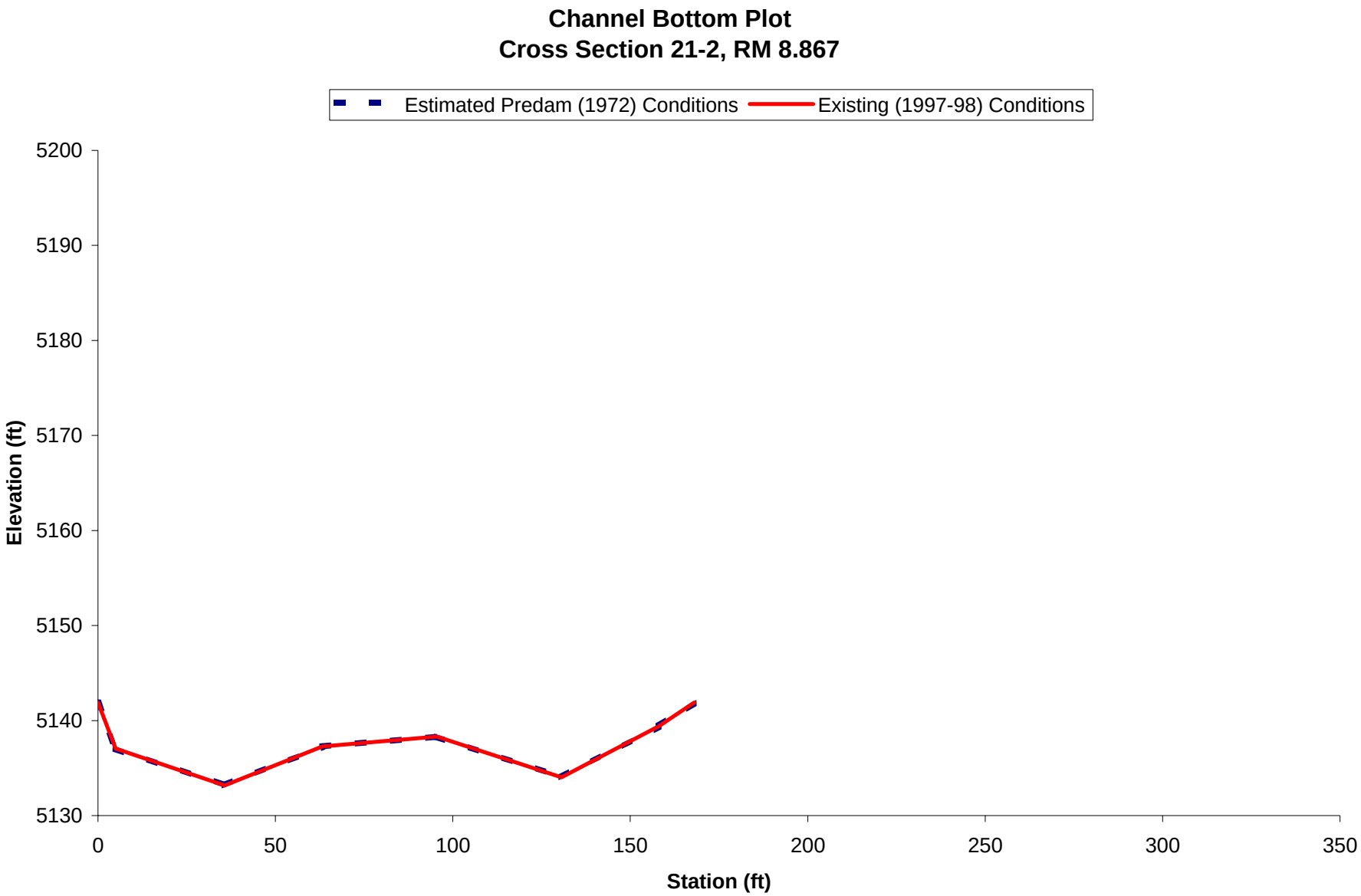

Channel Bottom Plot
Cross Section 19-3, RM 9.281
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

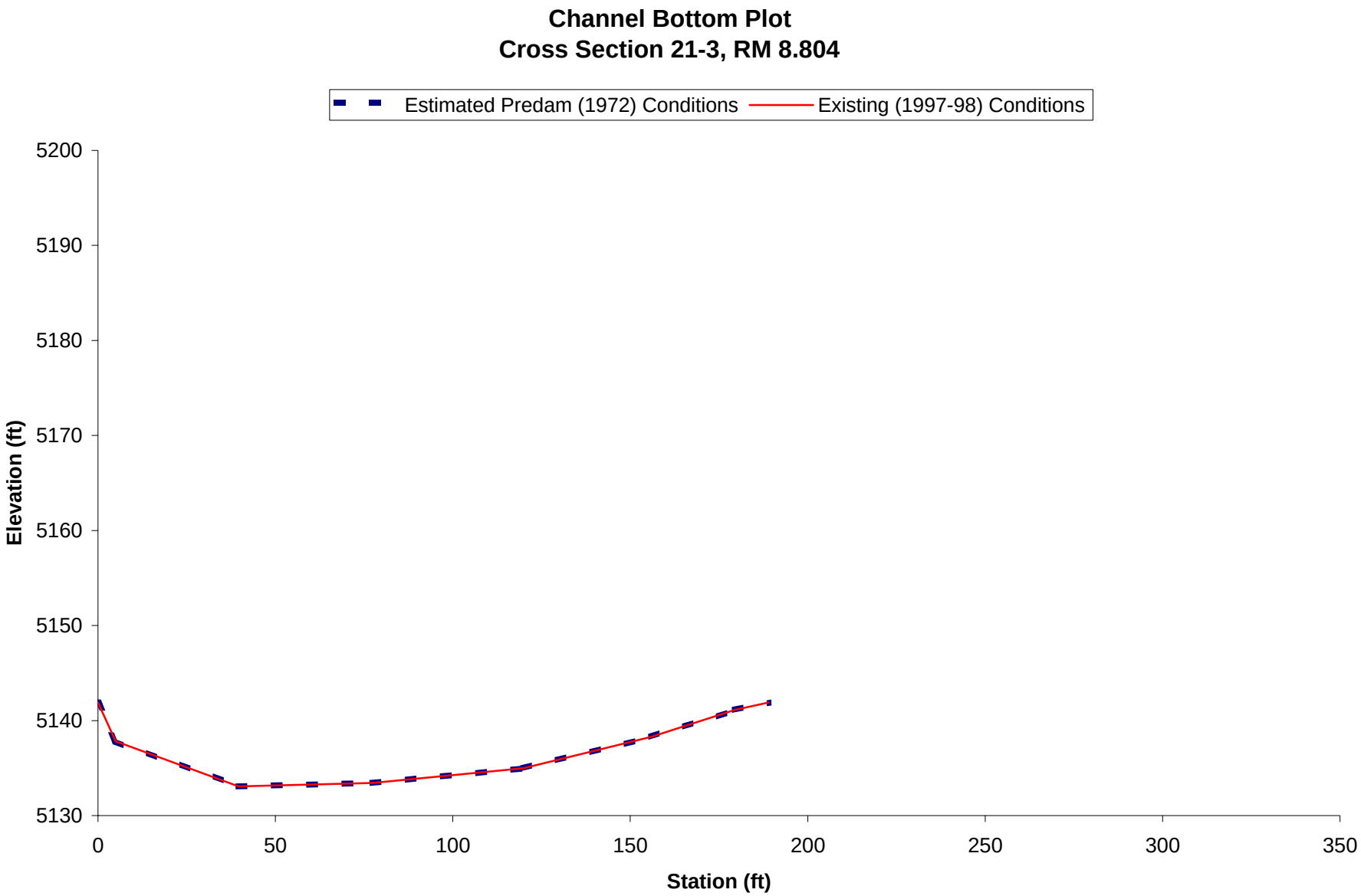

Channel Bottom Plot
Cross Section 19-4, RM 9.248
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

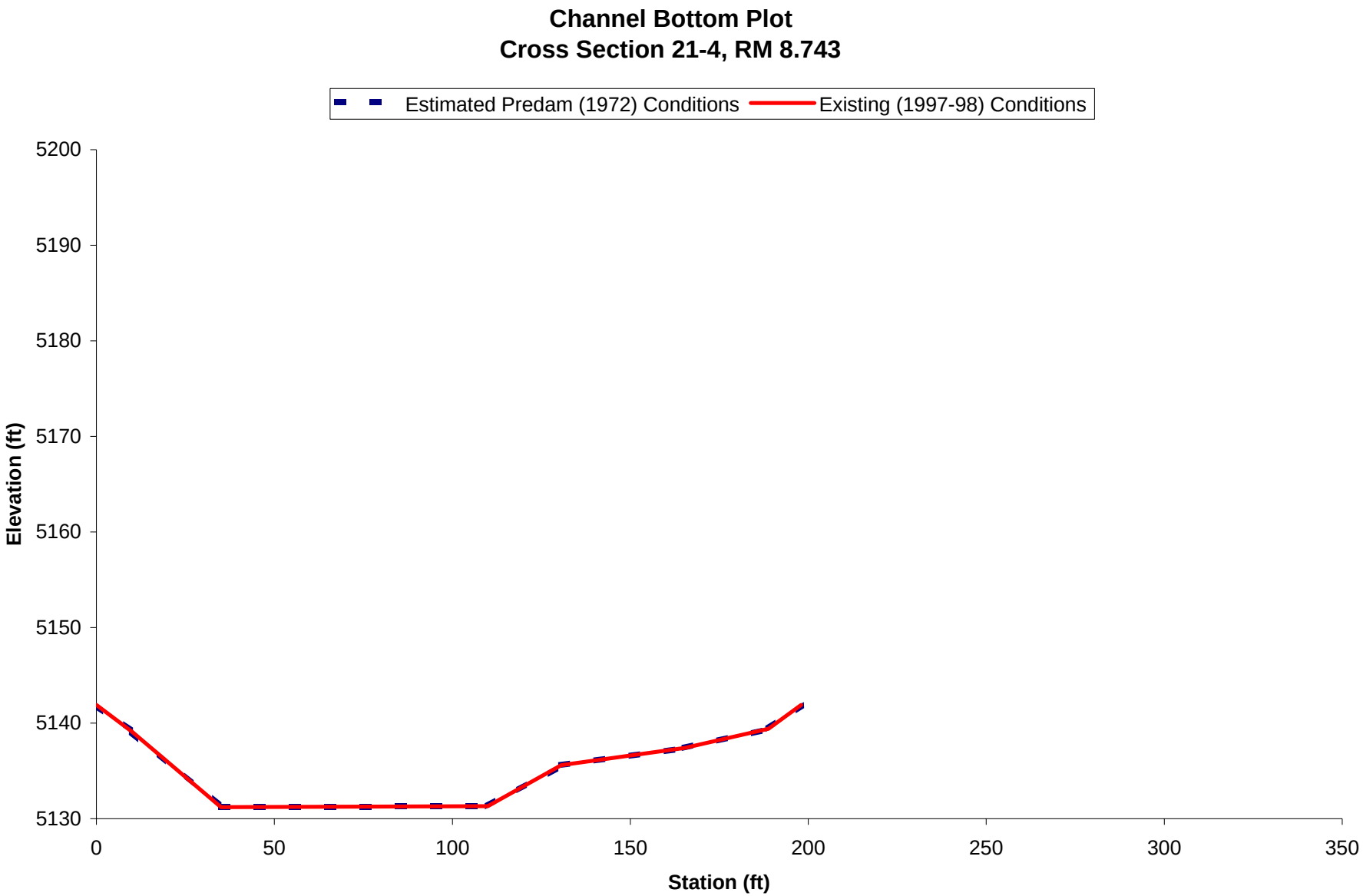

Channel Bottom Plot
Cross Section 20-1, RM 9.035
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

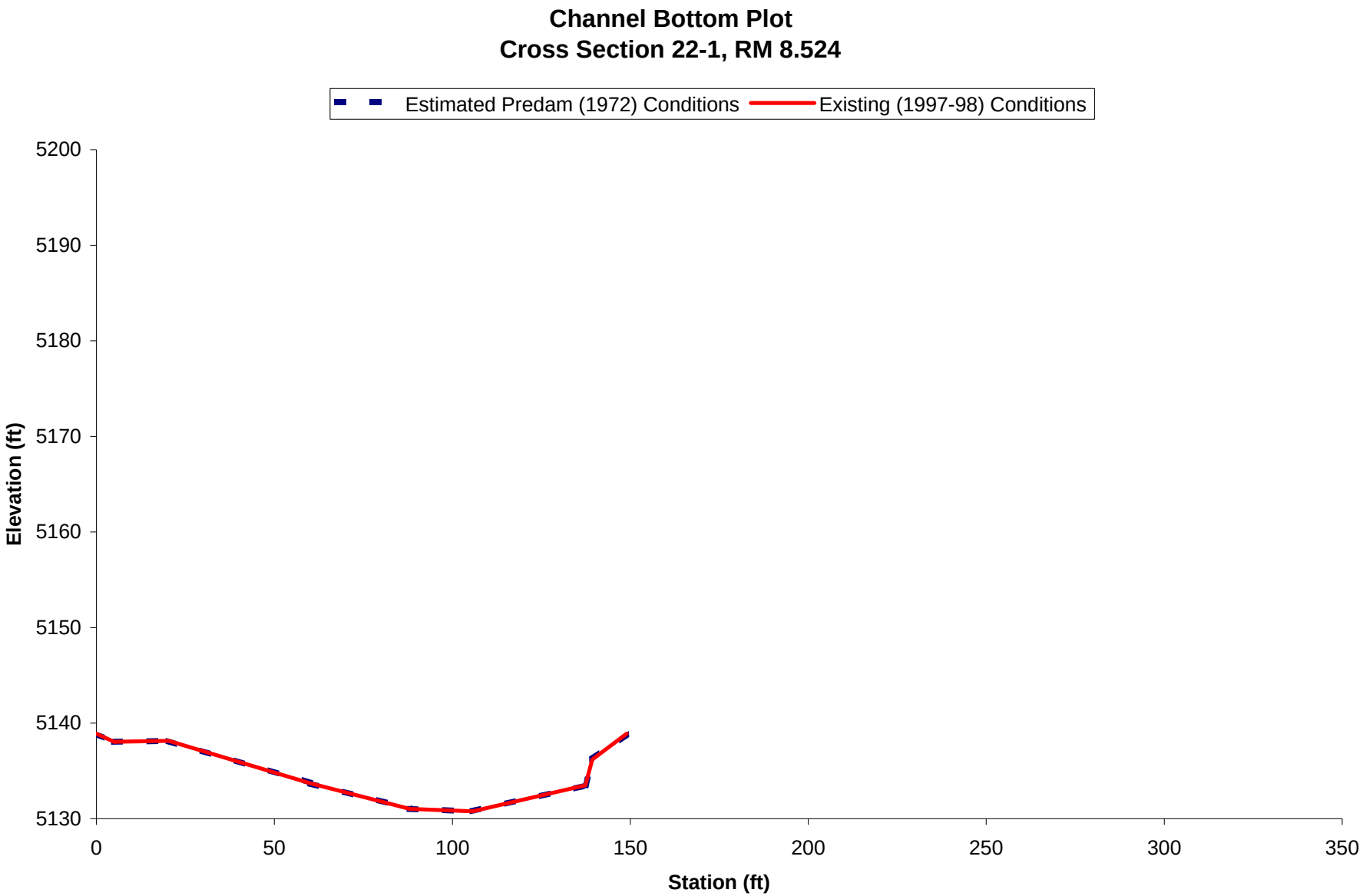

Channel Bottom Plot
Rapid 20
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5320
5300
5280
5260
5240
5220
5200
5180
5160
5140
5120
0
100
200
300
400
500
600
700
Station (ft)

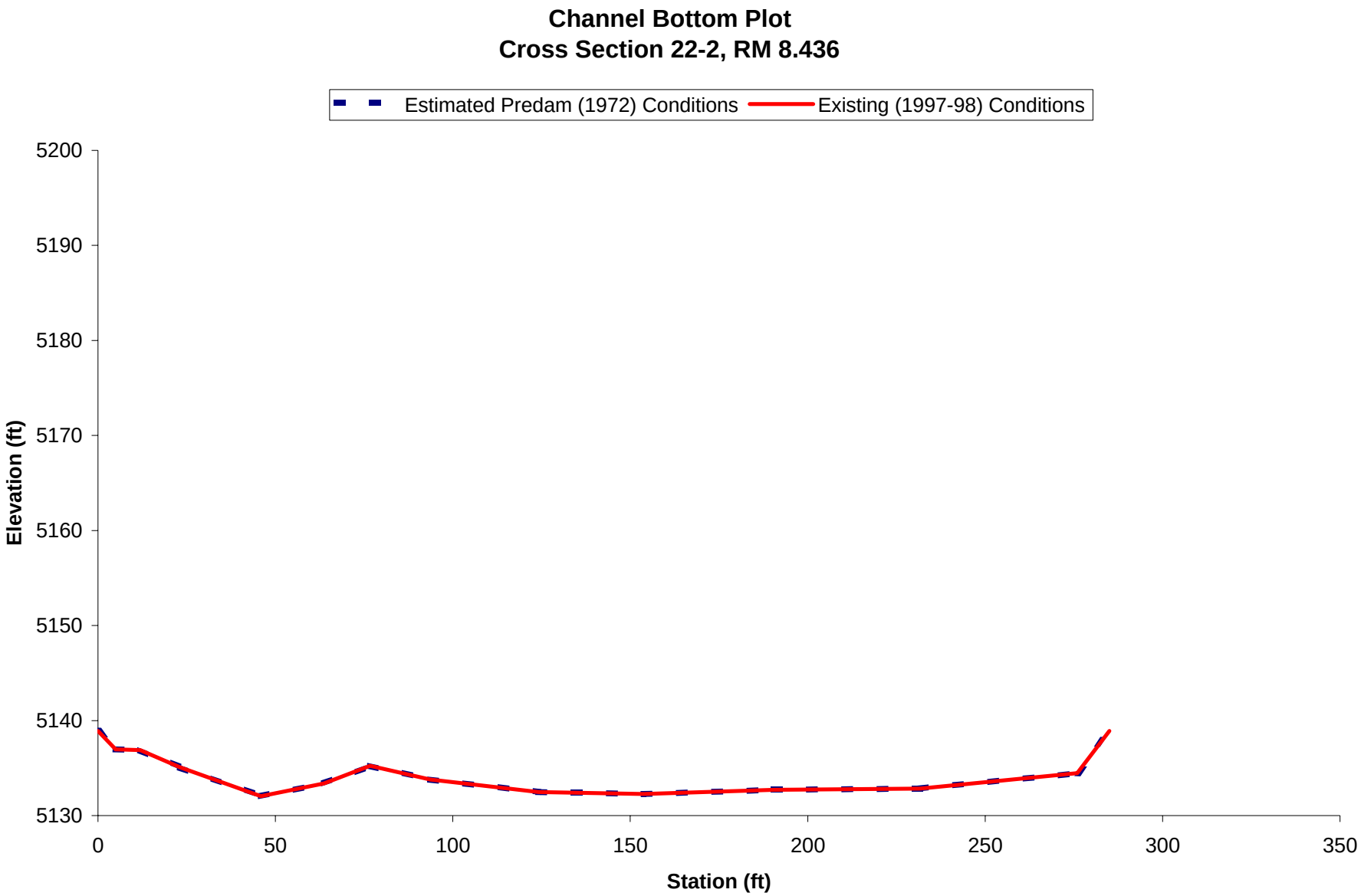

Channel Bottom Plot
Cross Section 21-1, RM 8.928
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

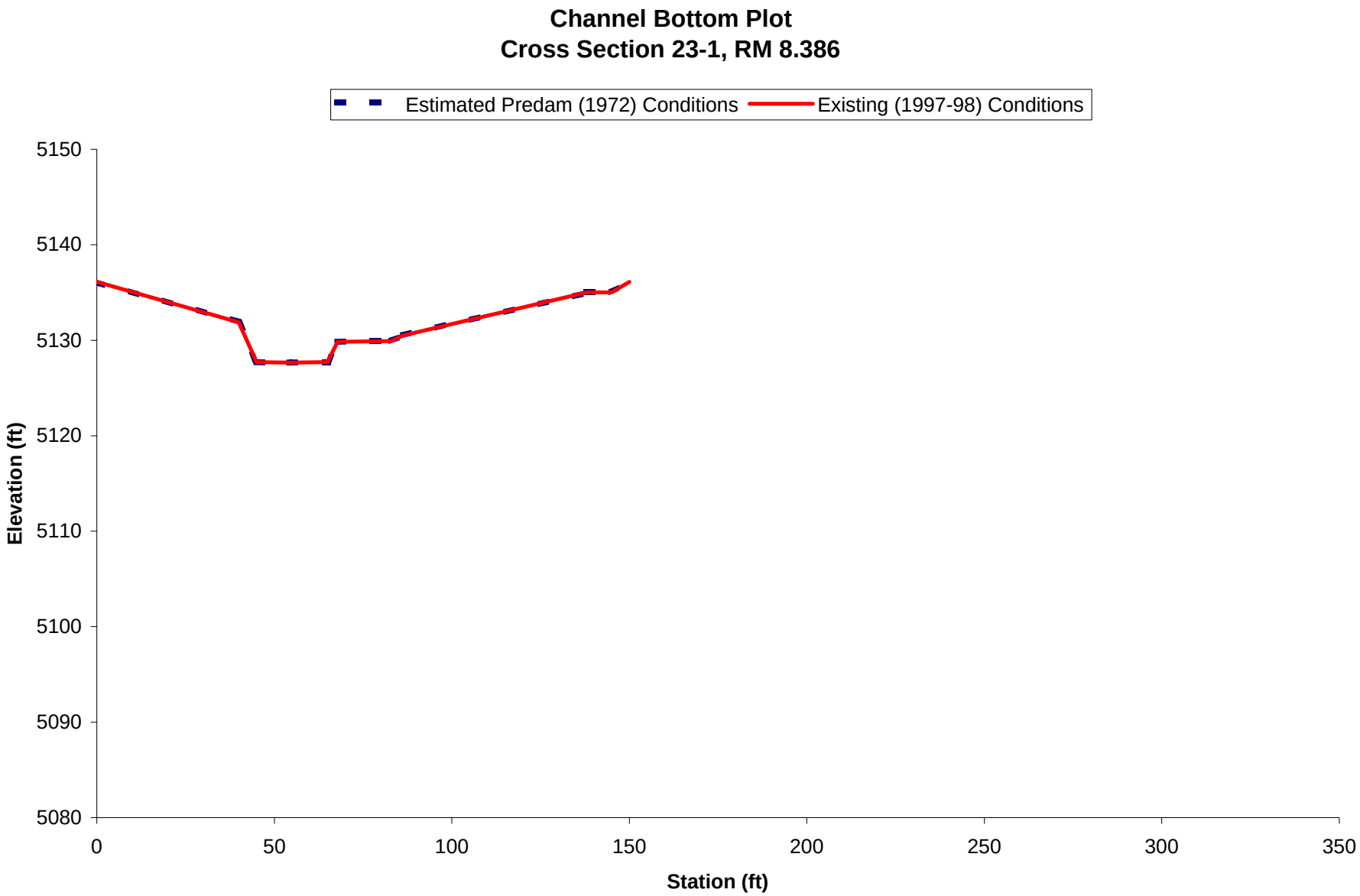

Channel Bottom Plot
Cross Section 21-2, RM 8.867
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

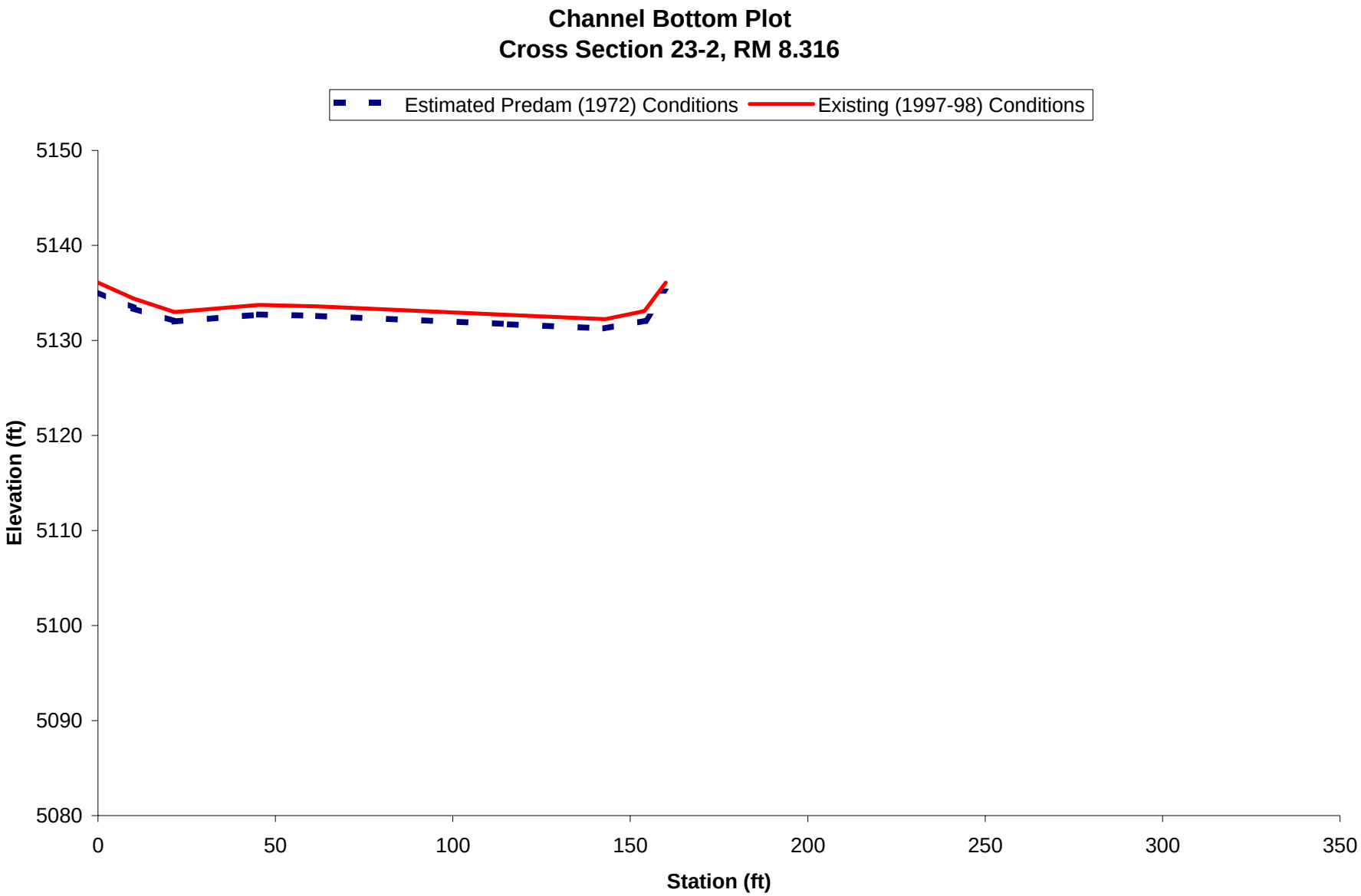

Channel Bottom Plot
Cross Section 21-3, RM 8.804
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

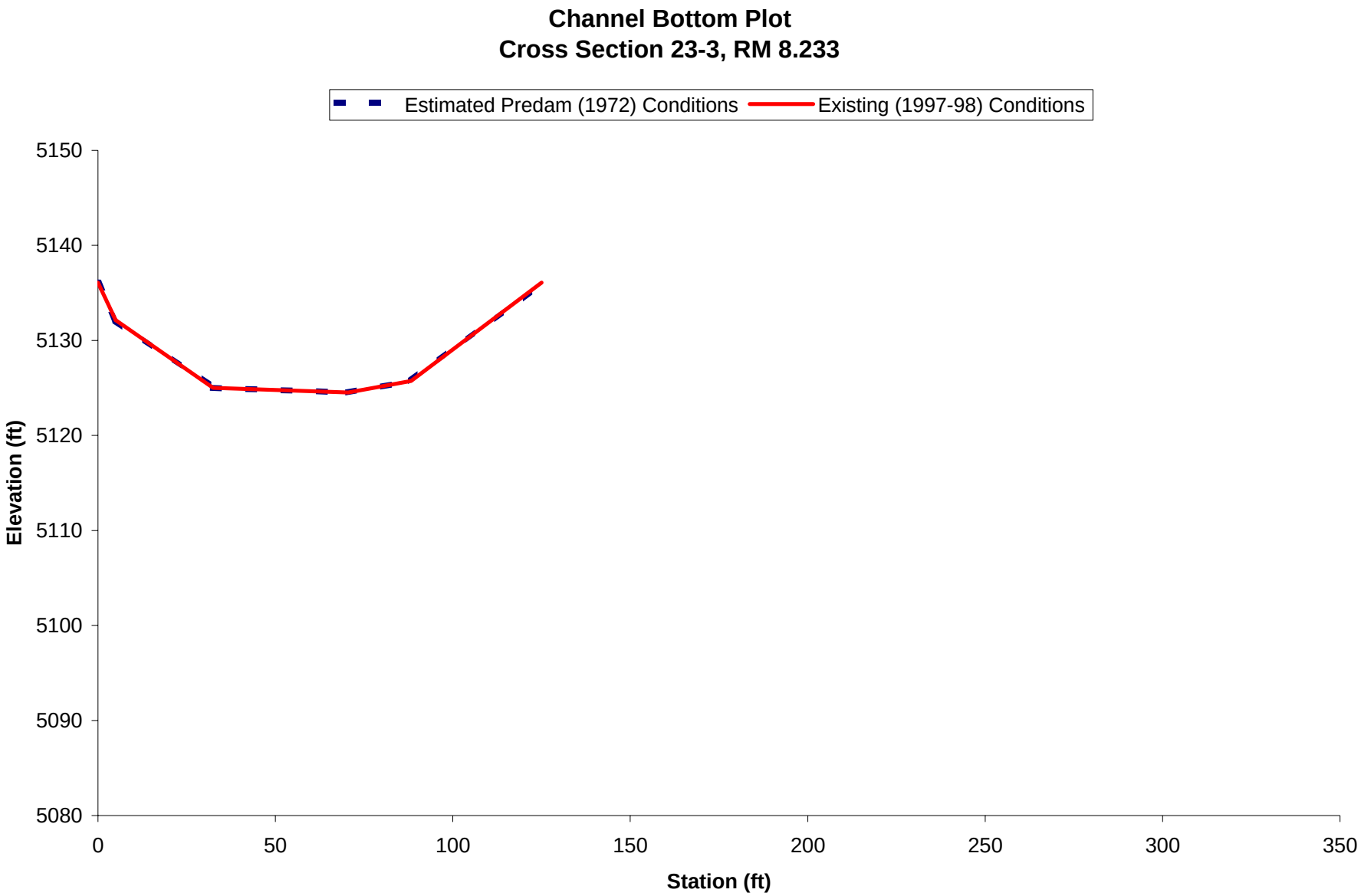

Channel Bottom Plot
Cross Section 21-4, RM 8.743
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

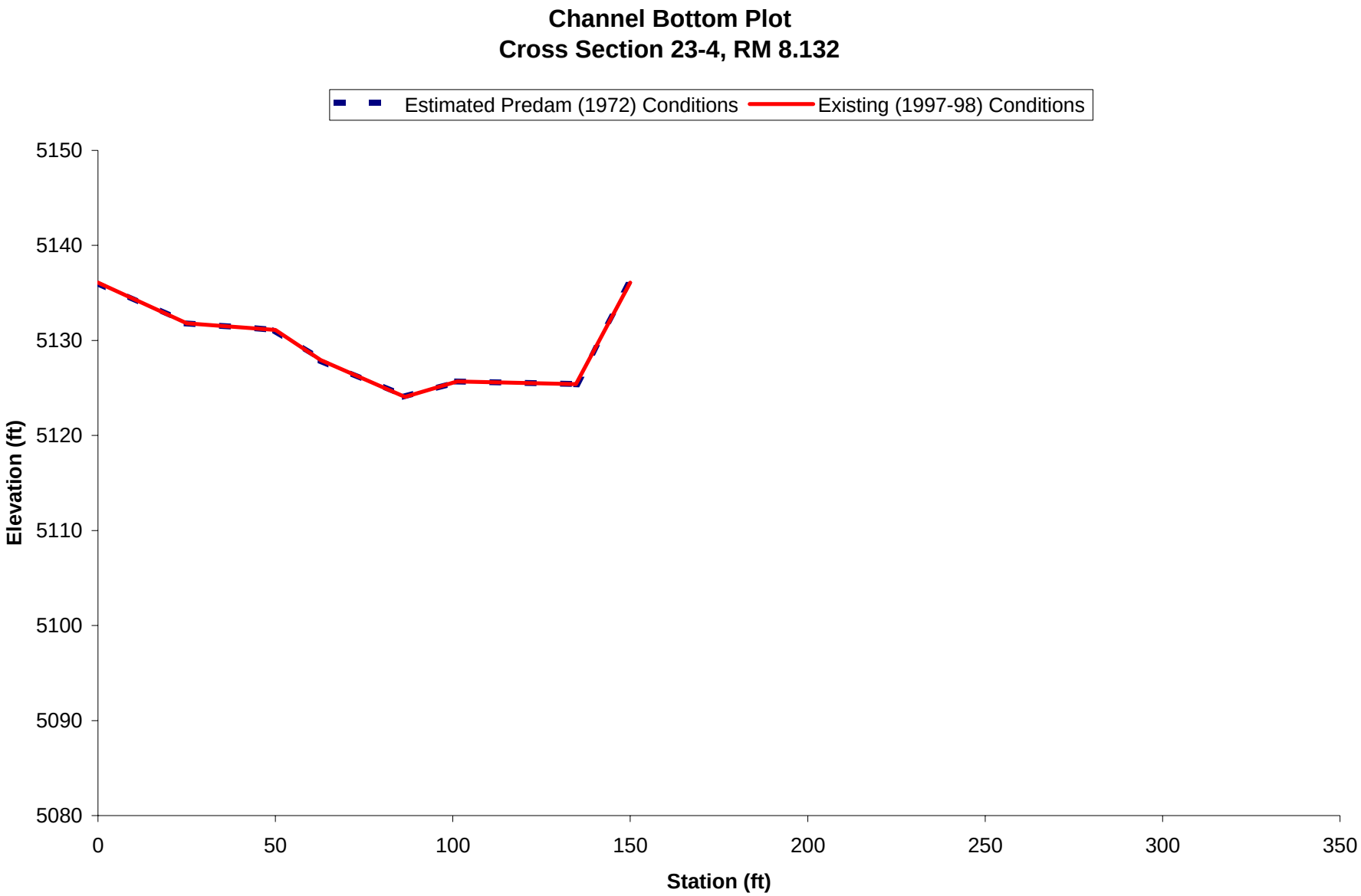

Channel Bottom Plot
Cross Section 22-1, RM 8.524
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

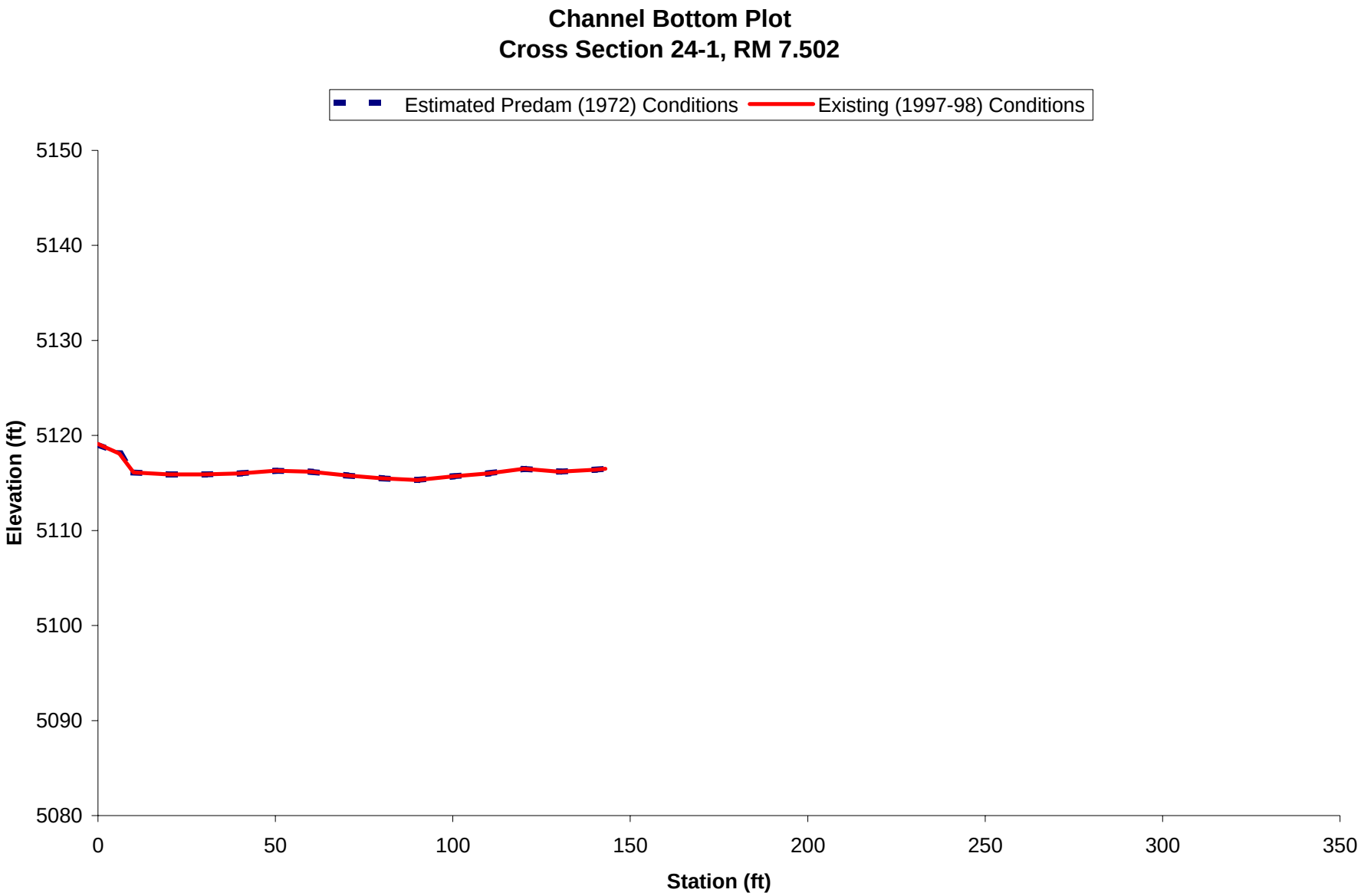

Channel Bottom Plot
Cross Section 22-2, RM 8.436
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5200
5190
5180
5170
5160
5150
5140
5130
0
50
100
150
200
250
300
350
Station (ft)

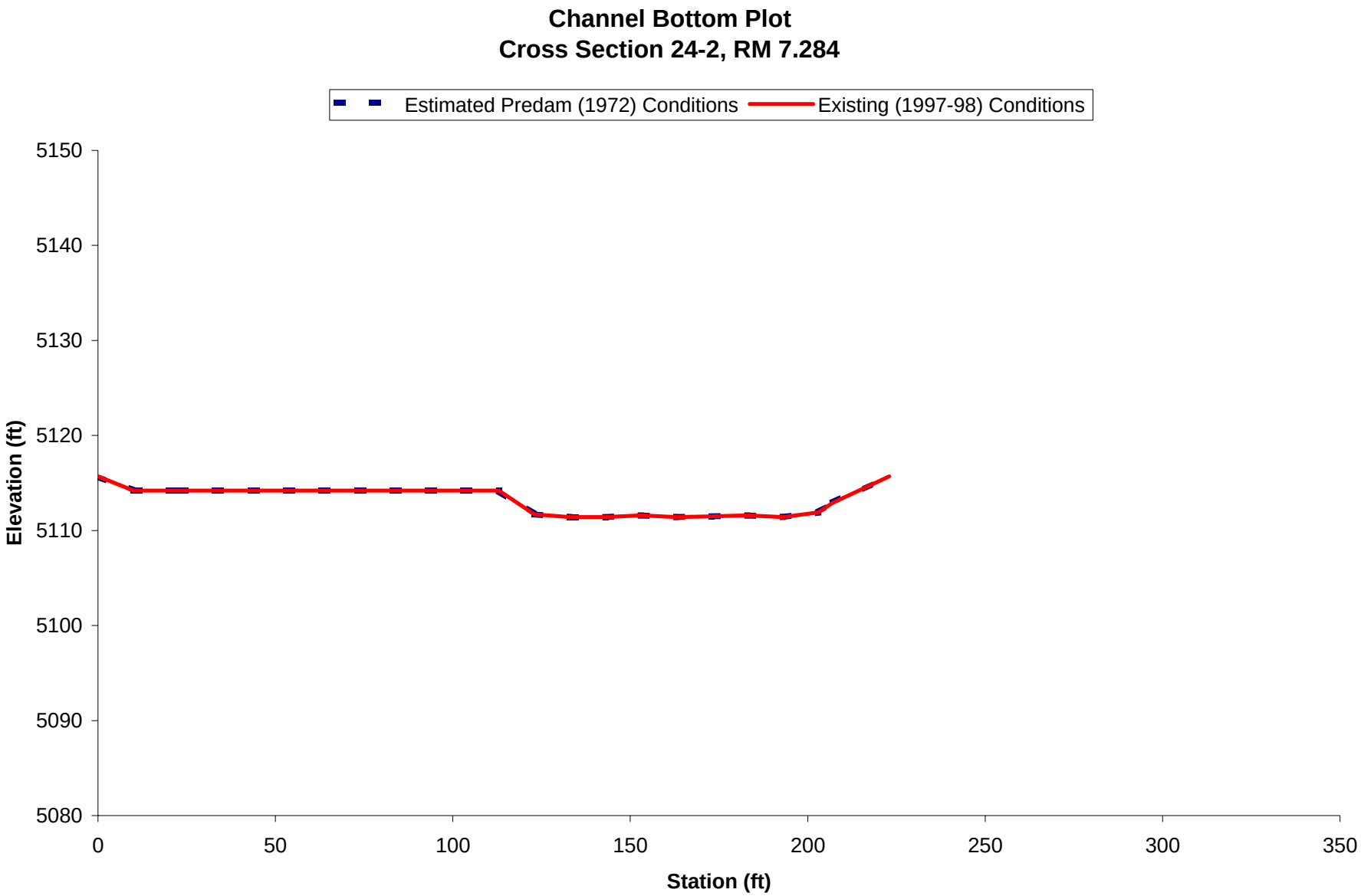

Channel Bottom Plot
Cross Section 23-1, RM 8.386
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

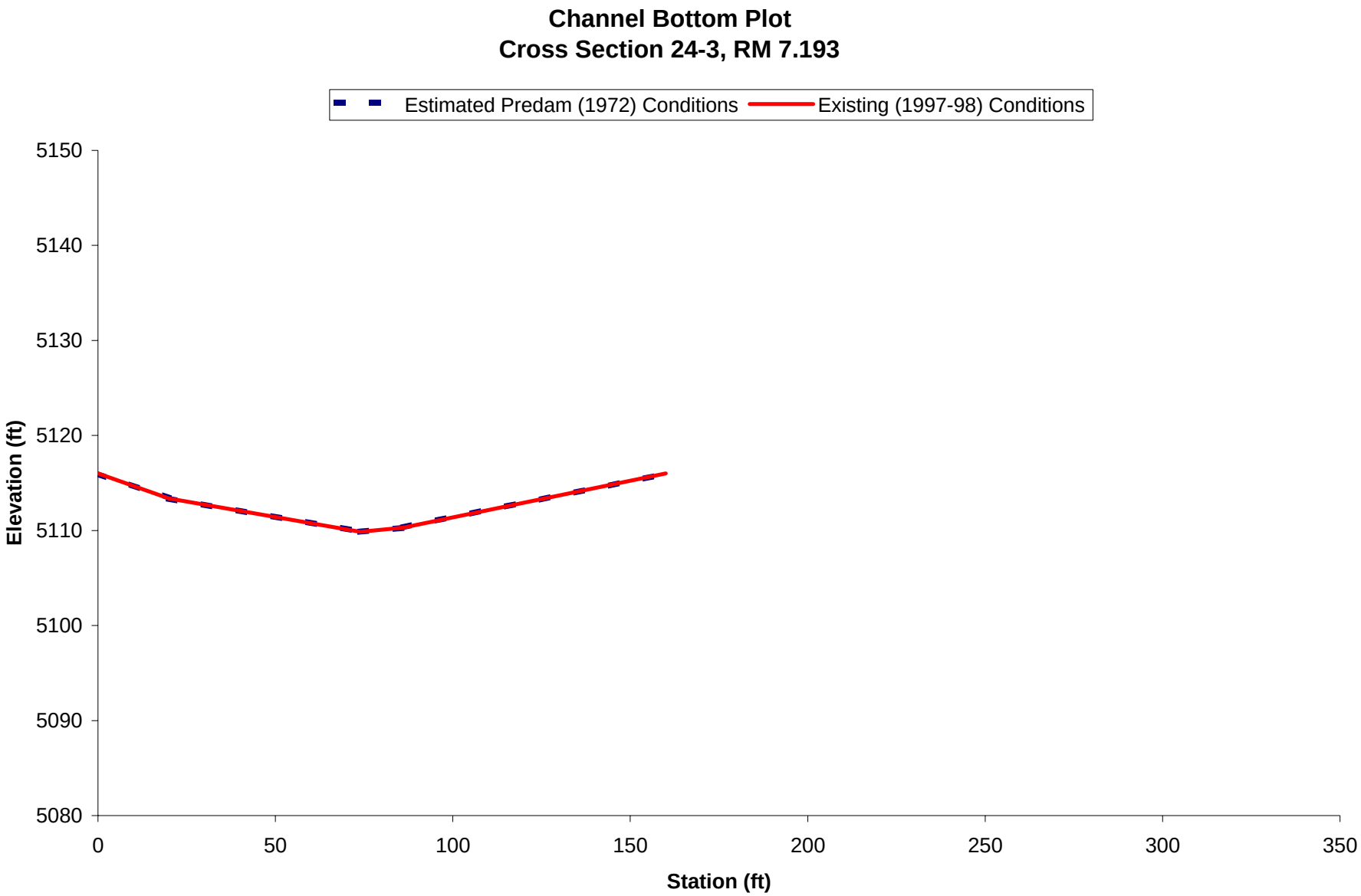

Channel Bottom Plot
Cross Section 23-2, RM 8.316
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

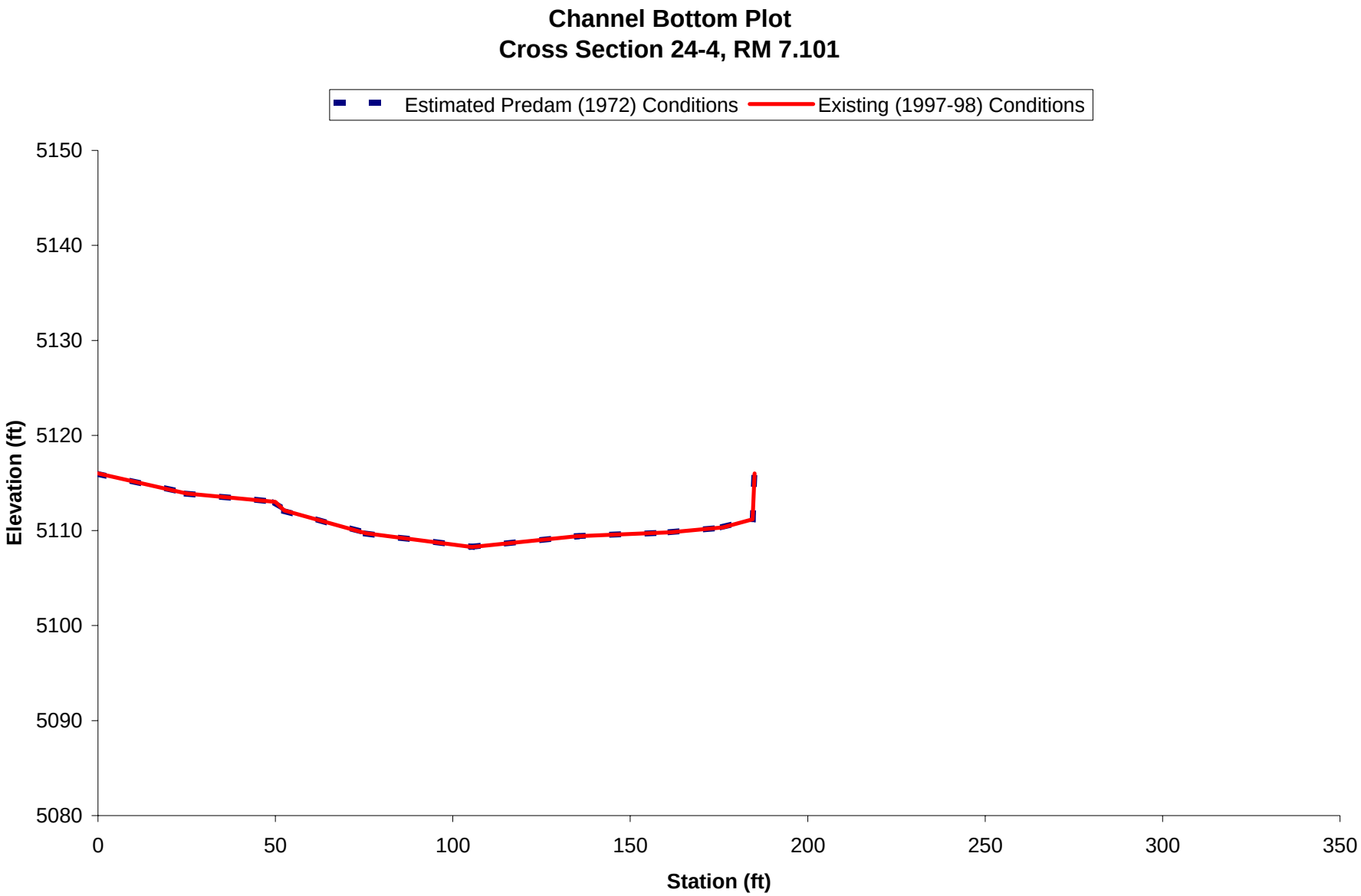

Channel Bottom Plot
Cross Section 23-3, RM 8.233
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

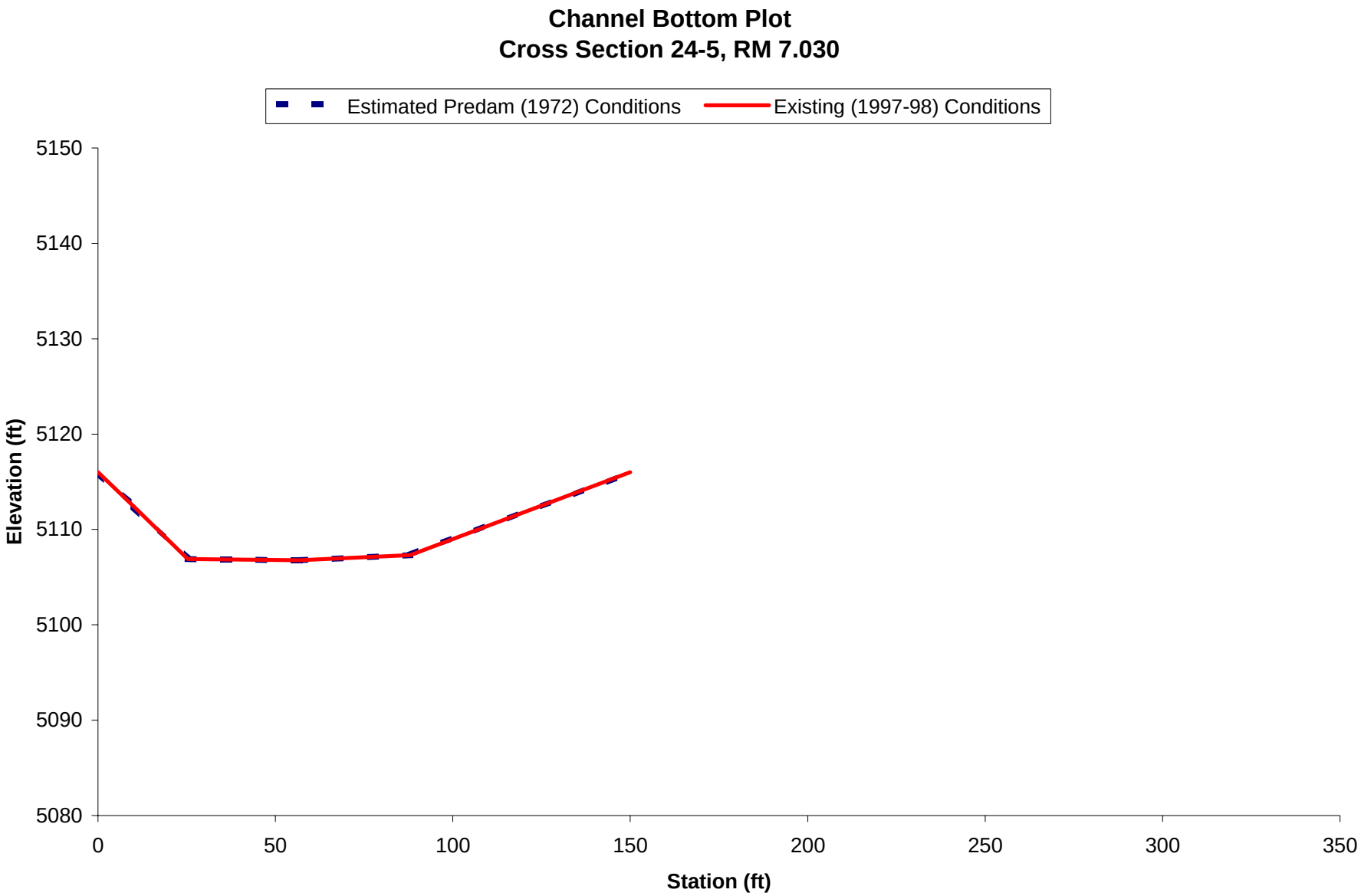

Channel Bottom Plot
Cross Section 23-4, RM 8.132
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

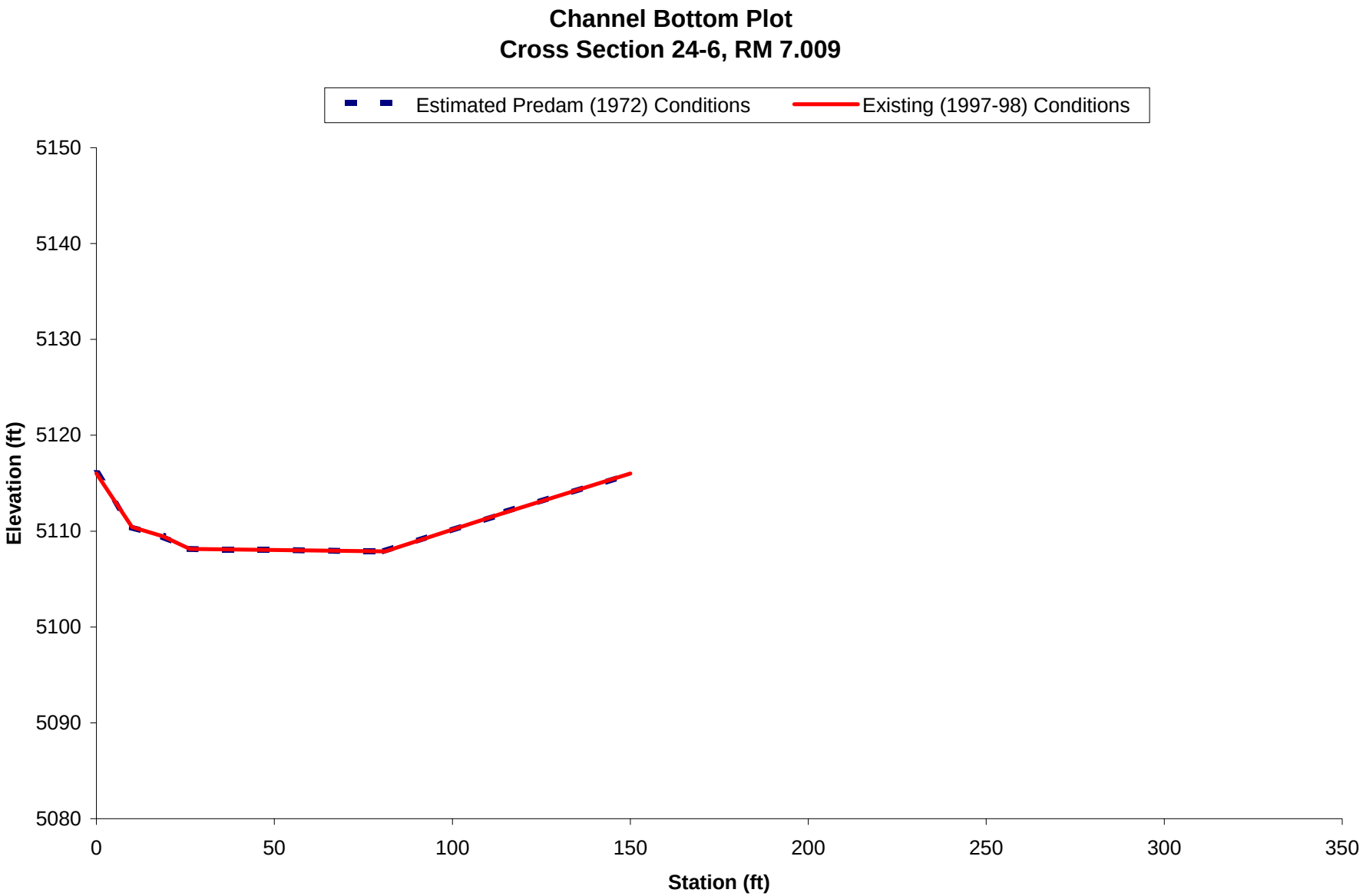

Channel Bottom Plot
Cross Section 24-1, RM 7.502
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

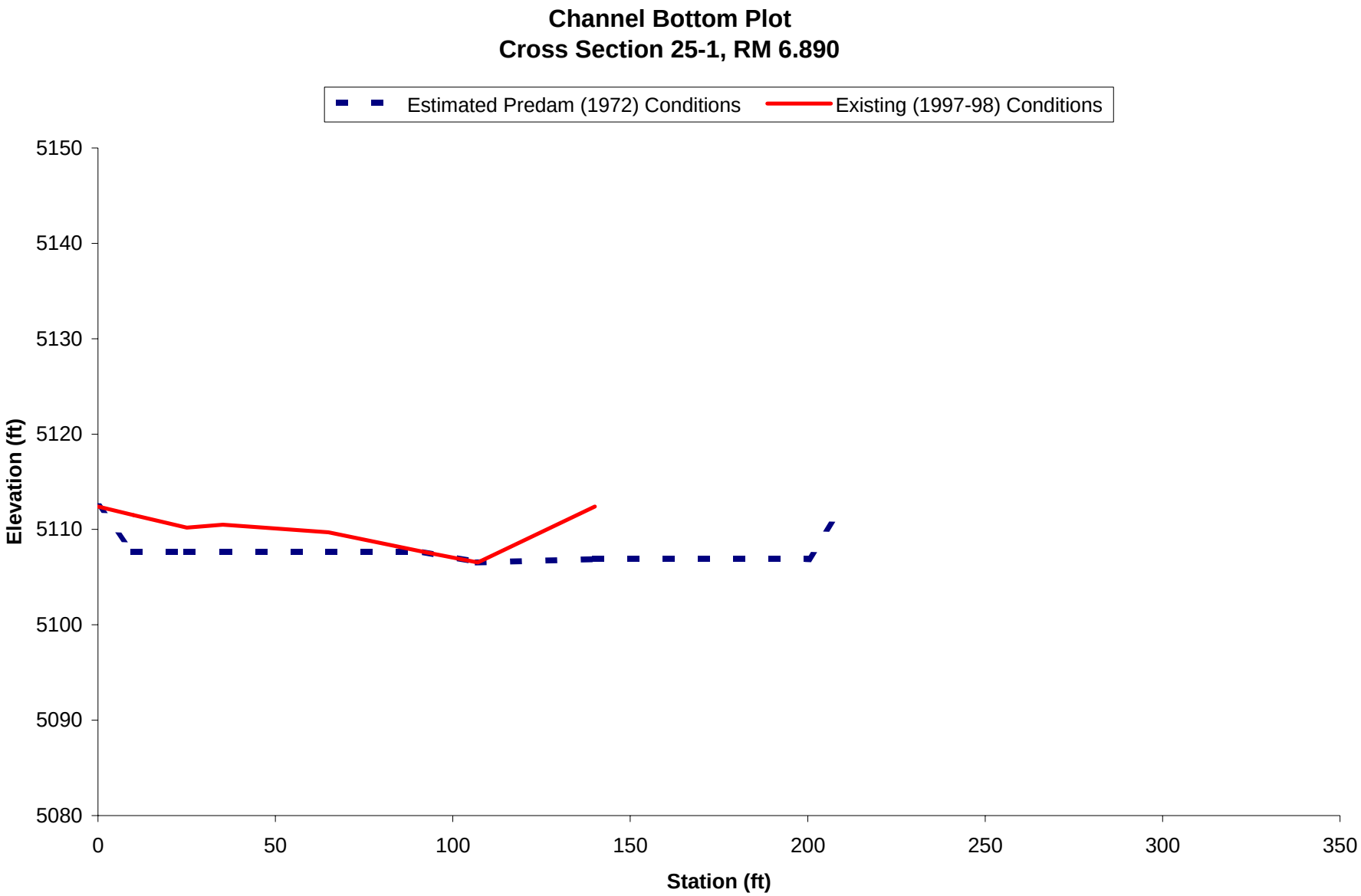

Channel Bottom Plot
Cross Section 24-2, RM 7.284
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

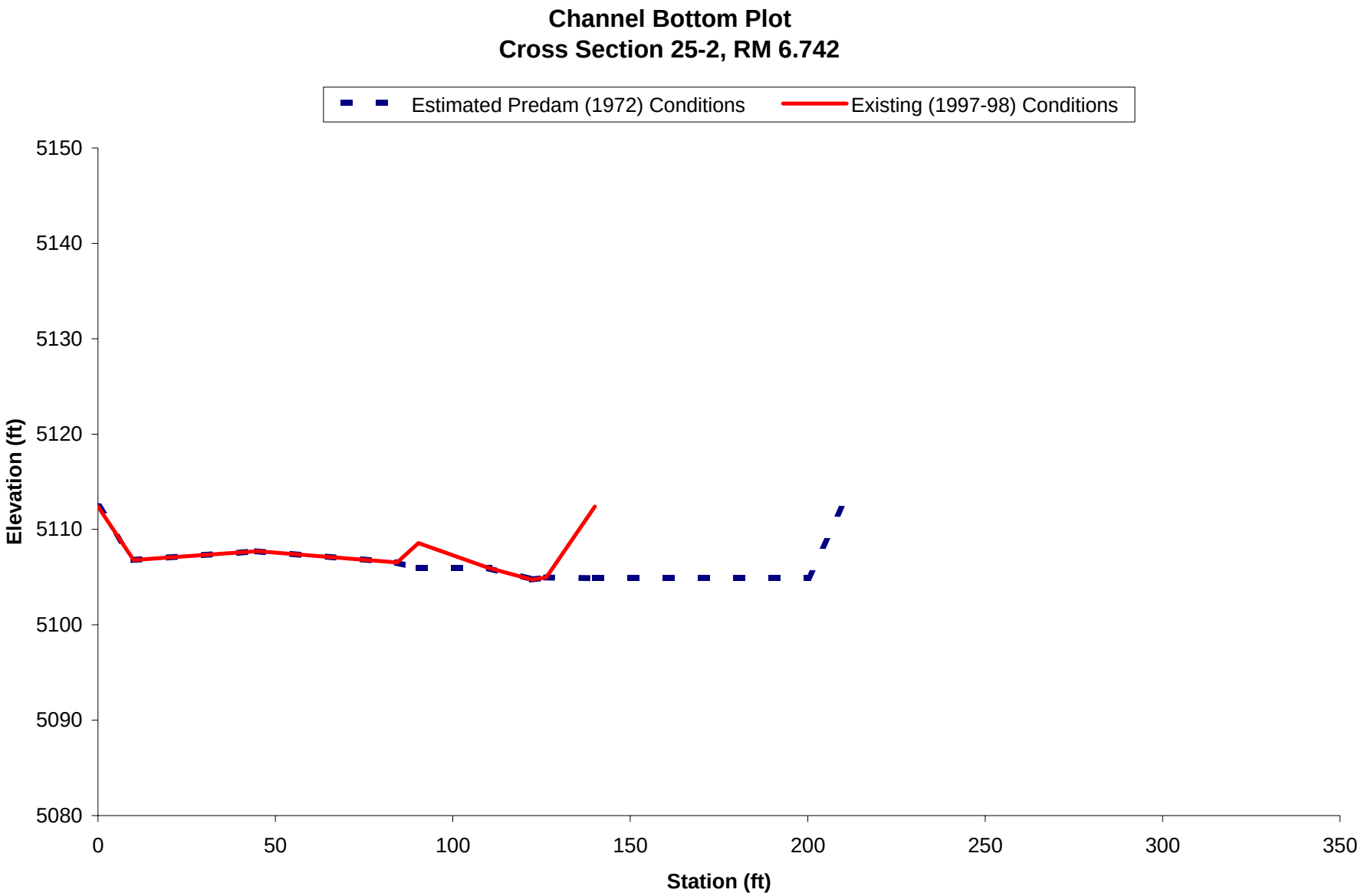

Channel Bottom Plot
Cross Section 24-3, RM 7.193
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

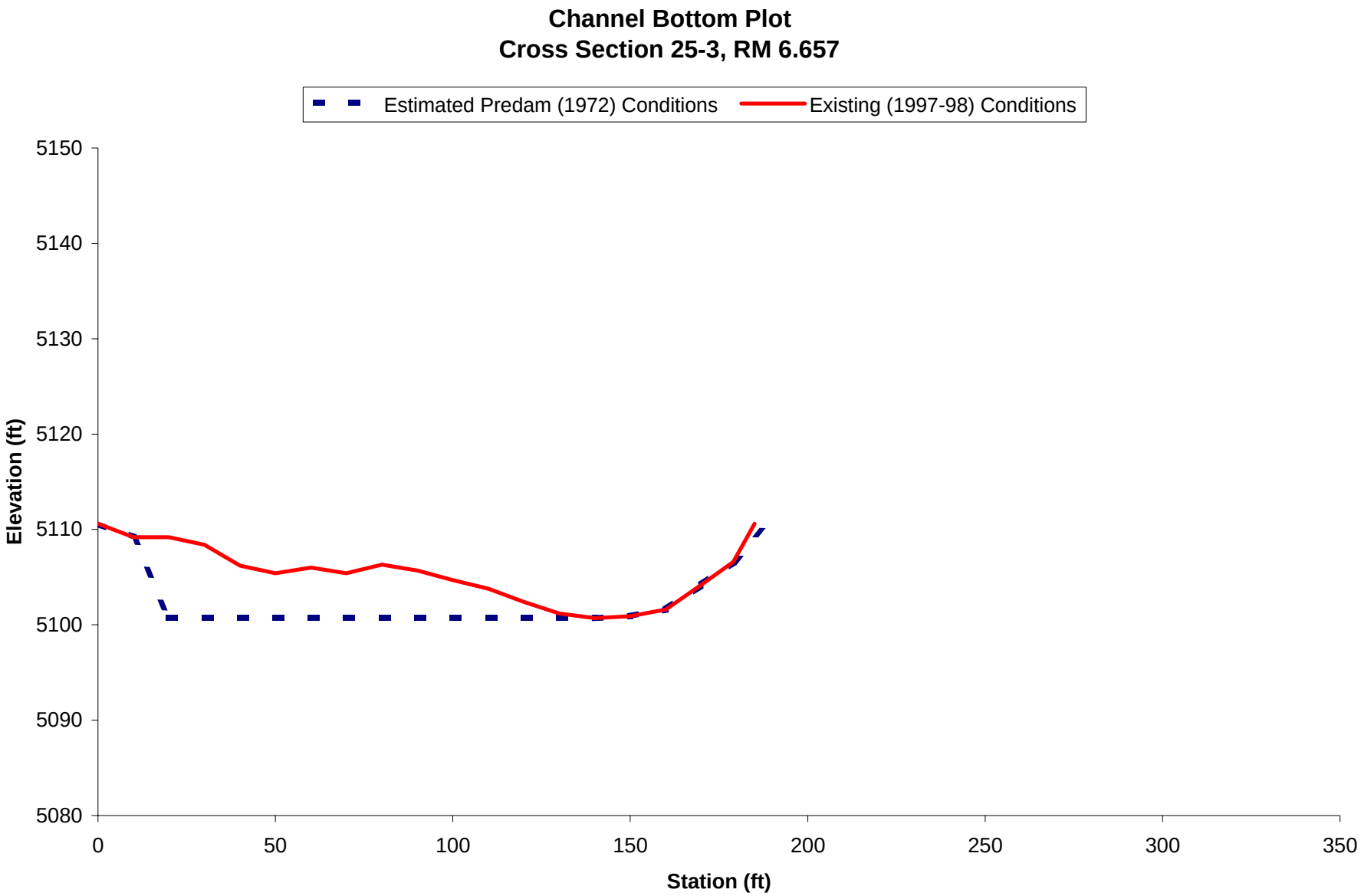

Channel Bottom Plot
Cross Section 24-4, RM 7.101
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

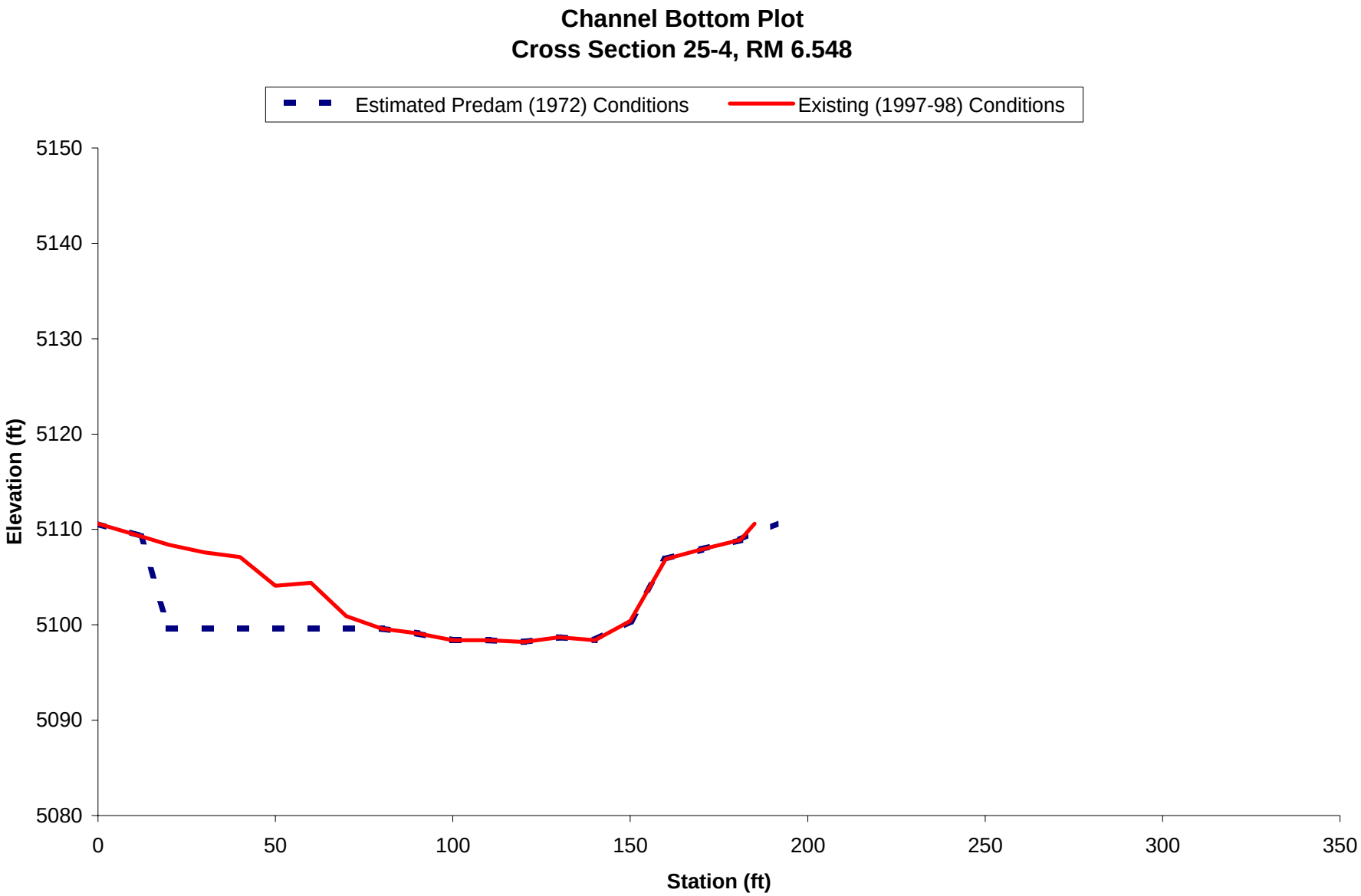

Channel Bottom Plot
Cross Section 24-5, RM 7.030
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

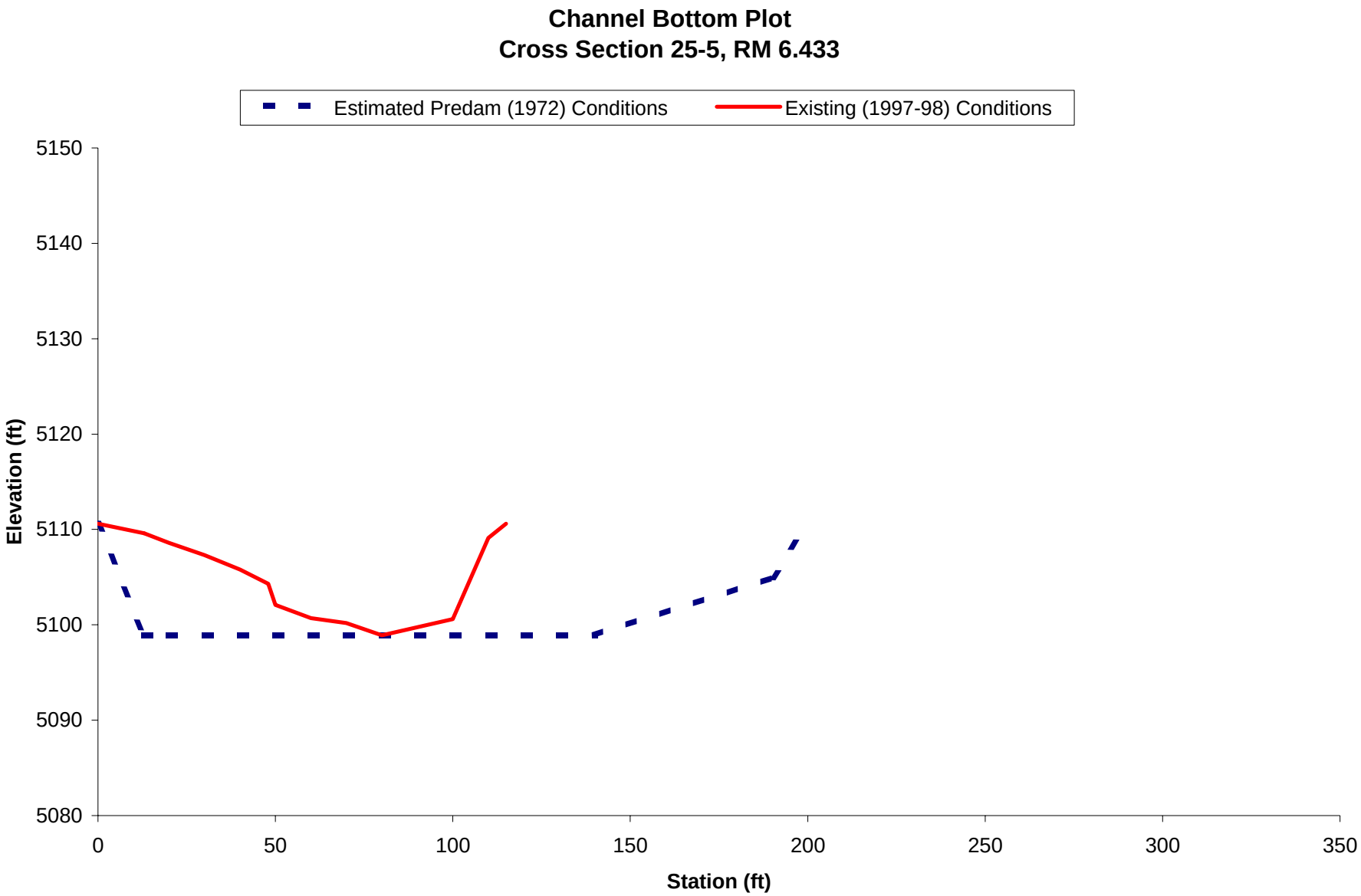

Channel Bottom Plot
Cross Section 24-6, RM 7.009
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

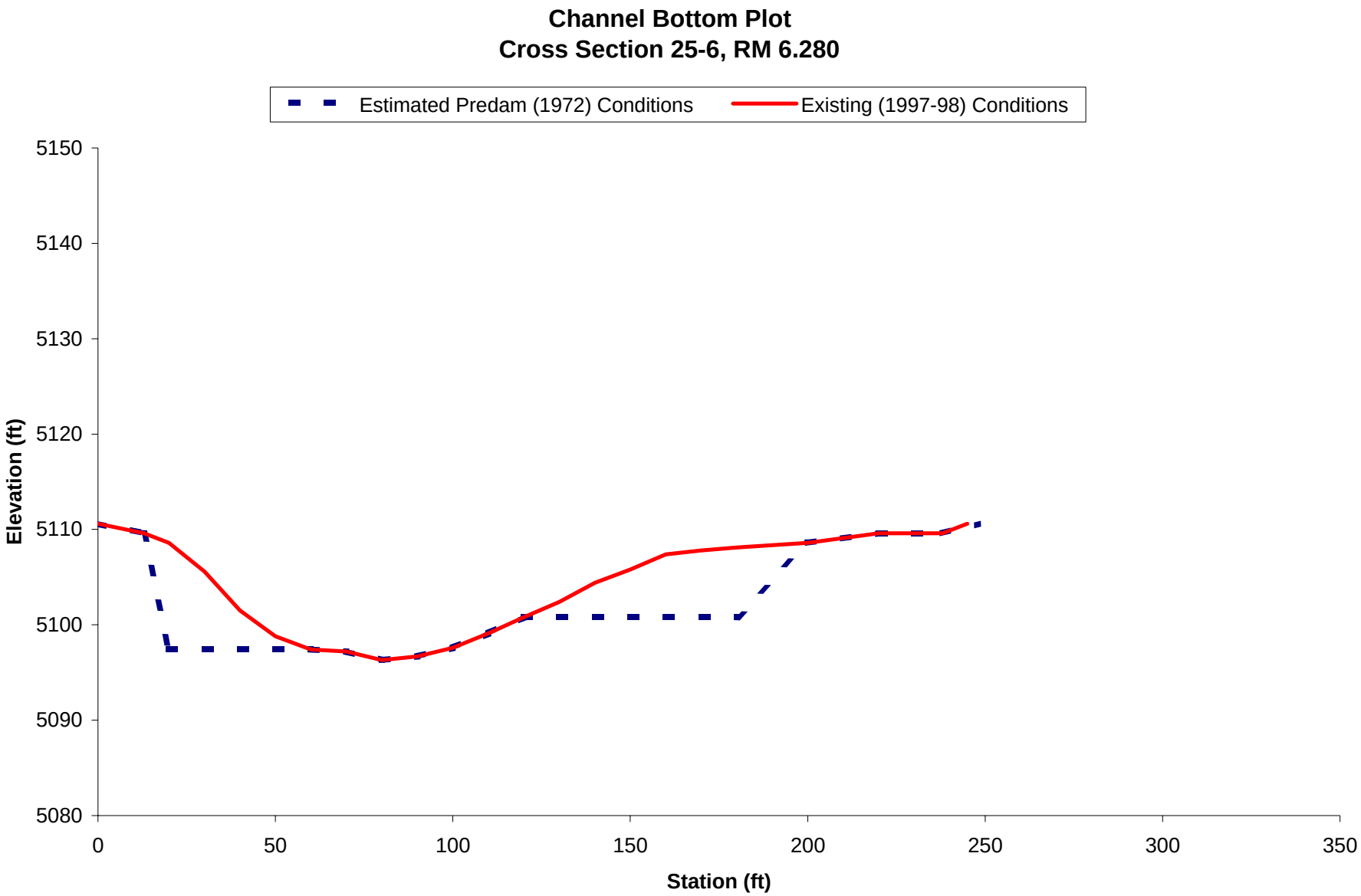

Channel Bottom Plot
Cross Section 25-1, RM 6.890
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

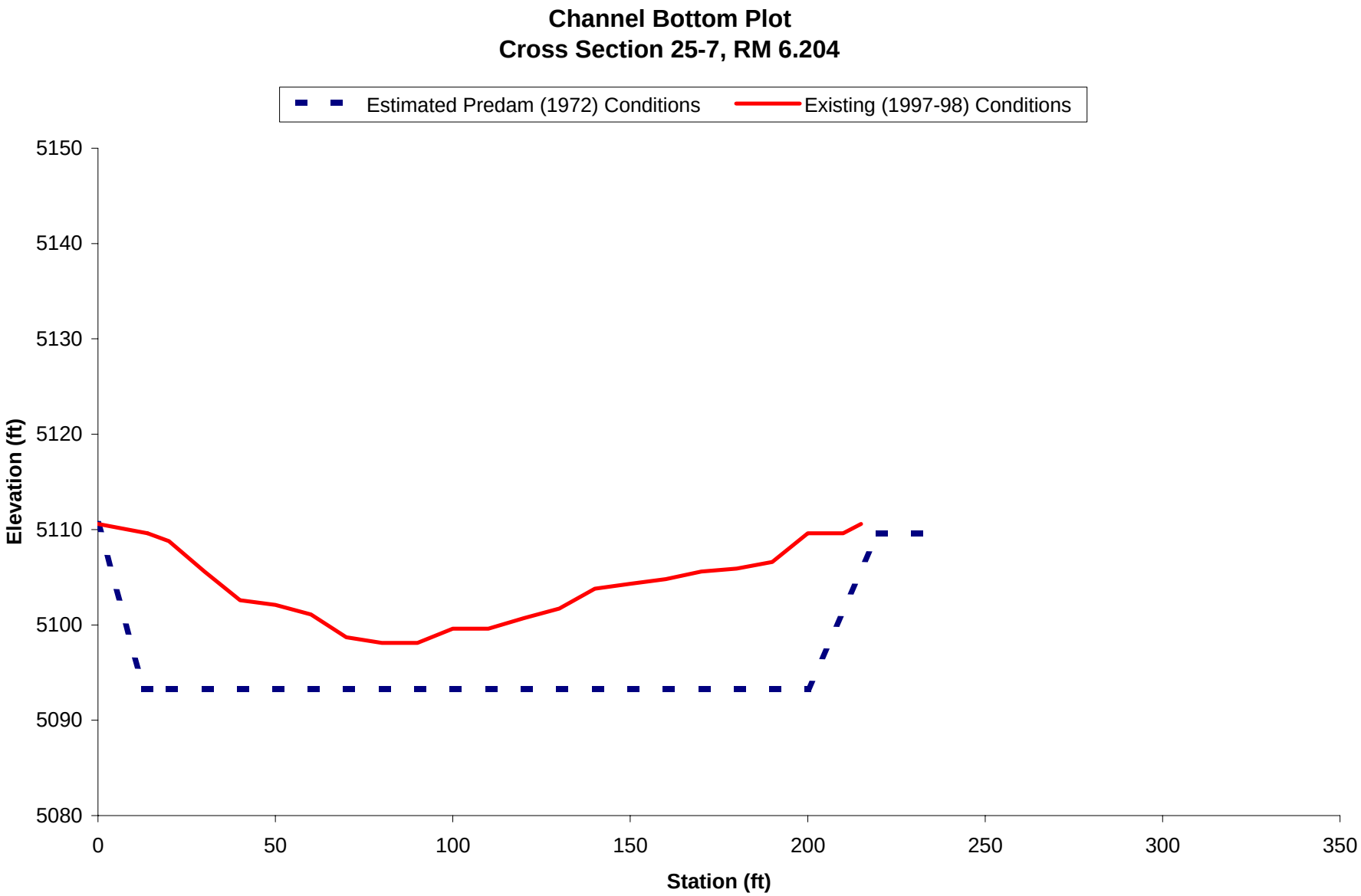

Channel Bottom Plot
Cross Section 25-2, RM 6.742
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

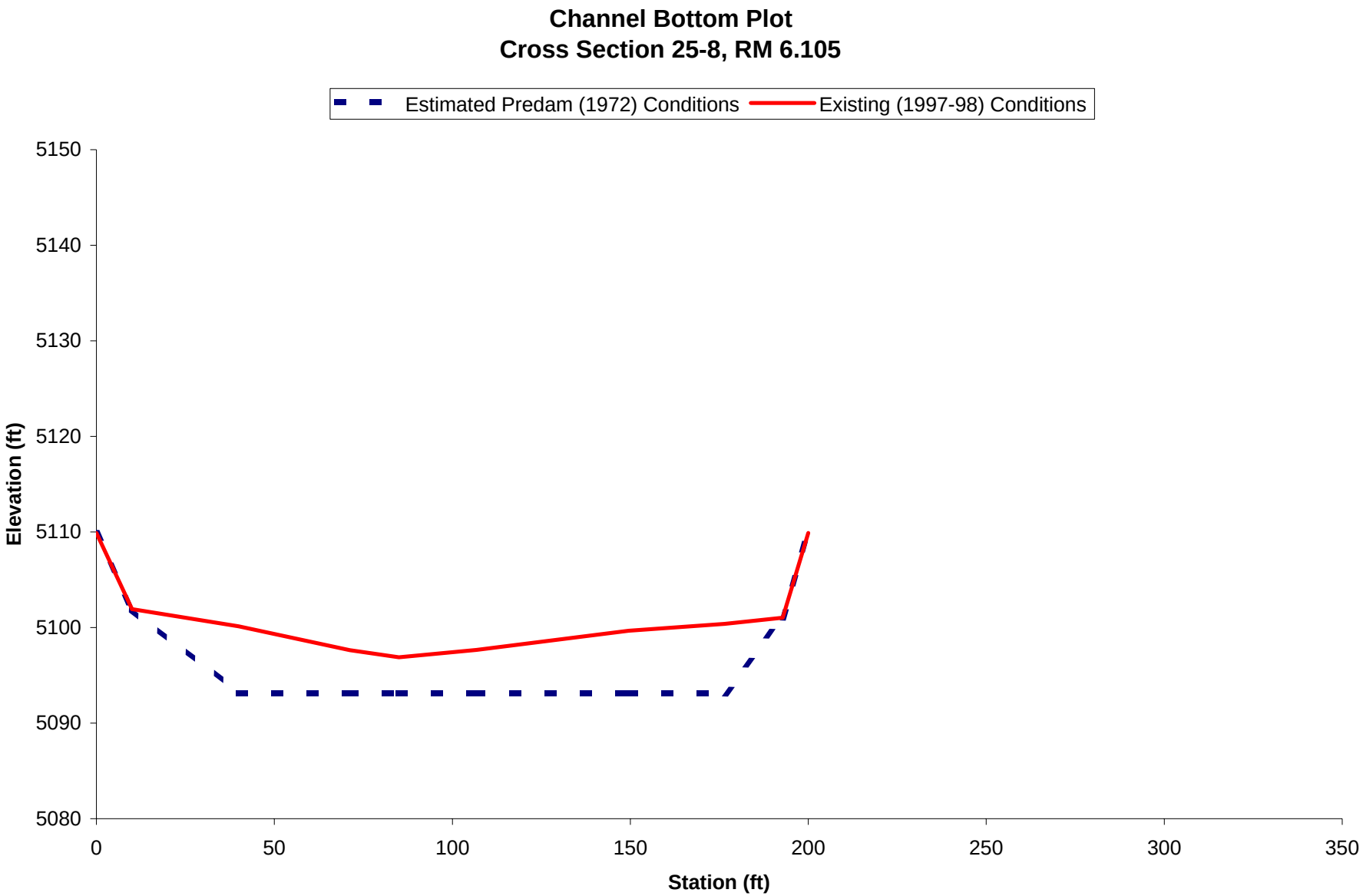

Channel Bottom Plot
Cross Section 25-3, RM 6.657
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

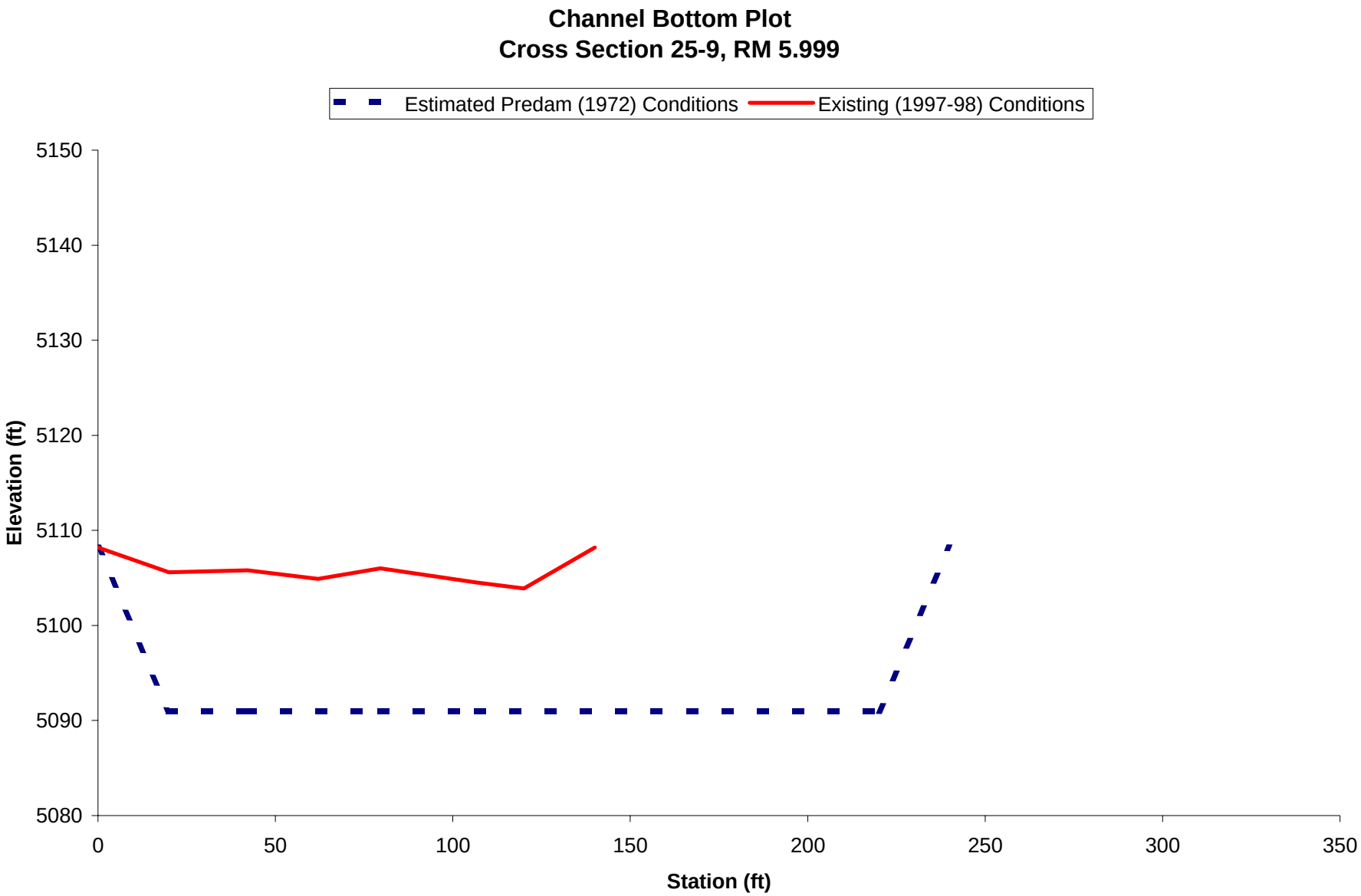

Channel Bottom Plot
Cross Section 25-4, RM 6.548
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

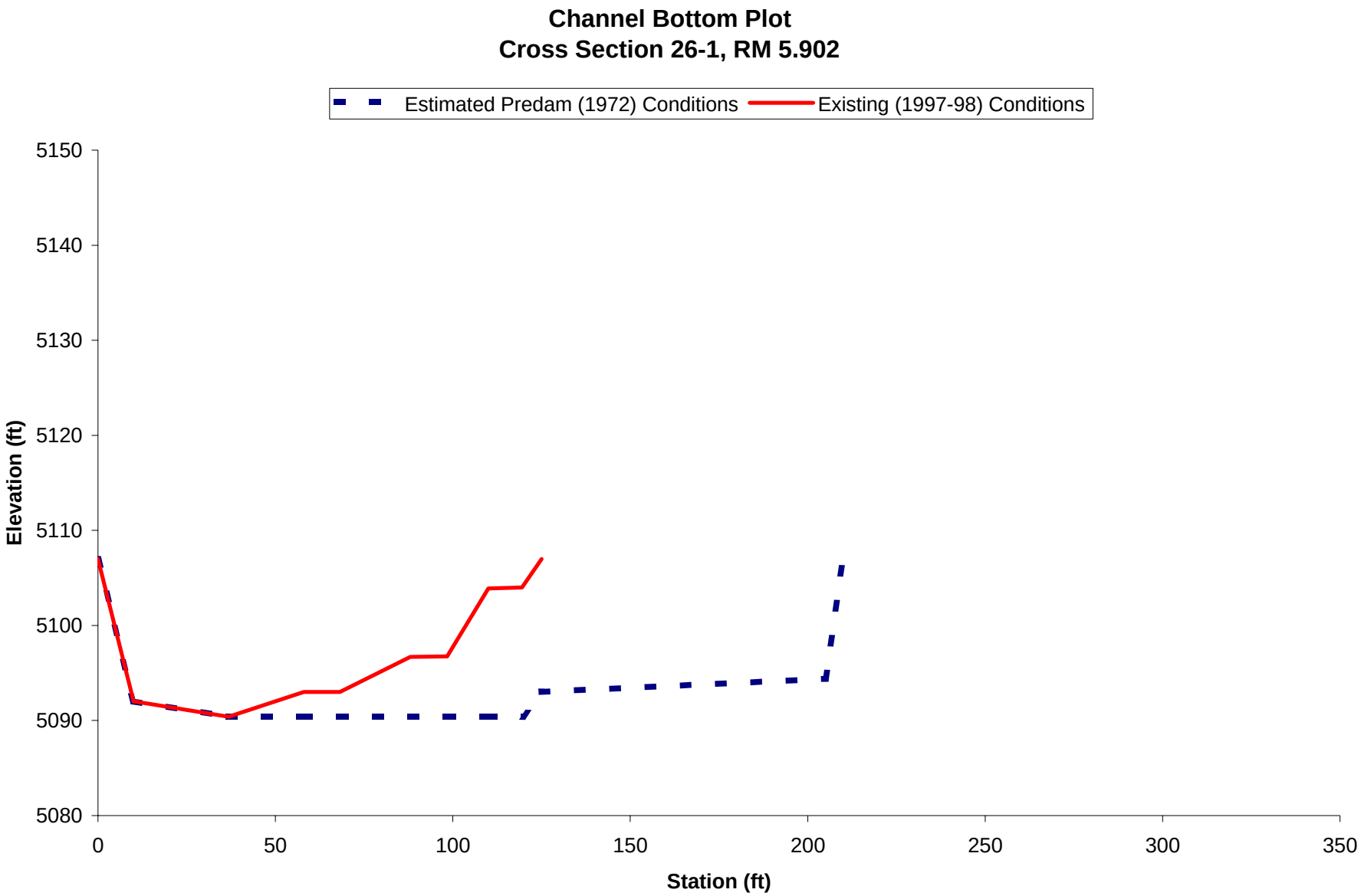

Channel Bottom Plot
Cross Section 25-5, RM 6.433
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

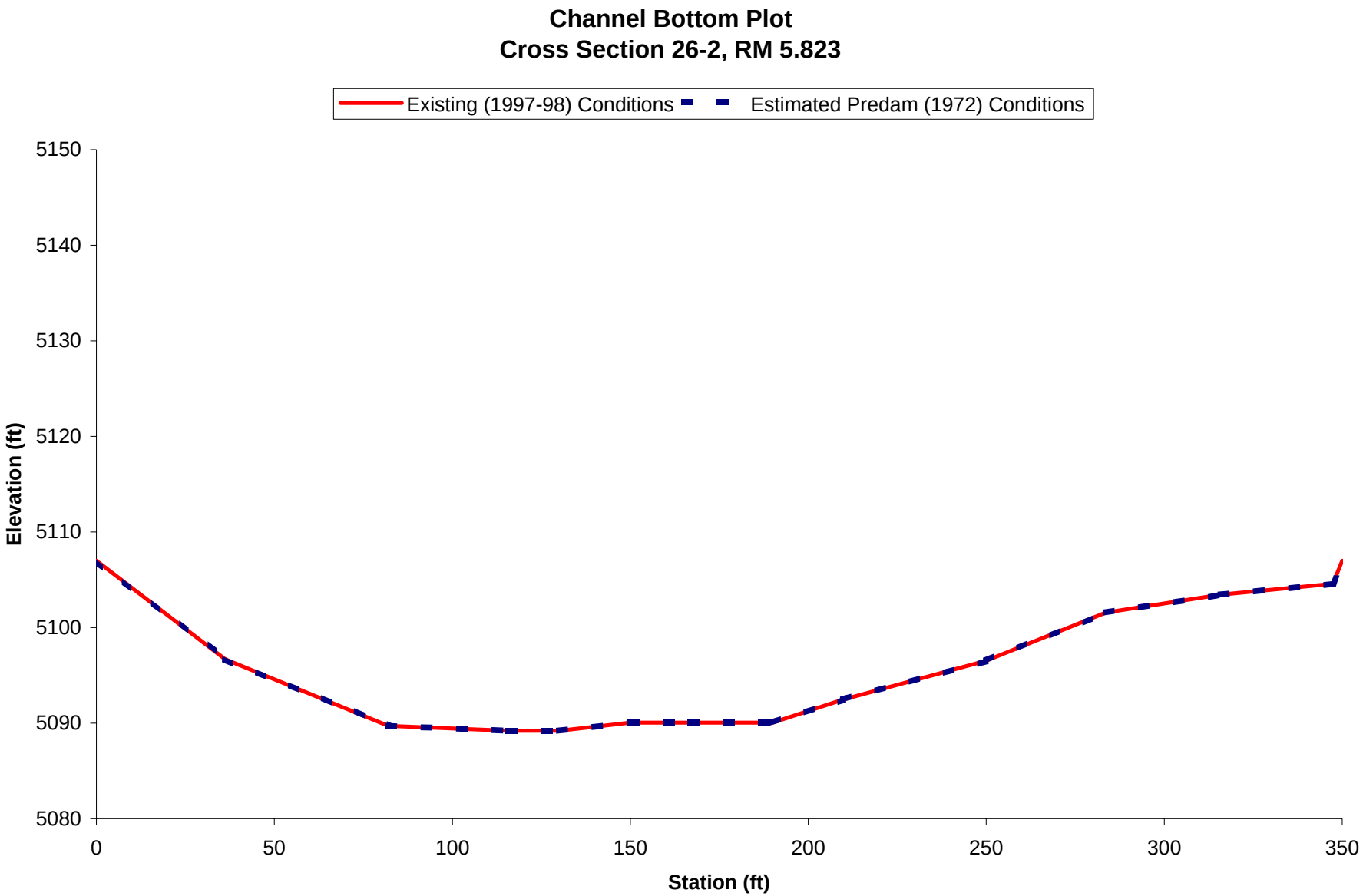

Channel Bottom Plot
Cross Section 25-6, RM 6.280
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

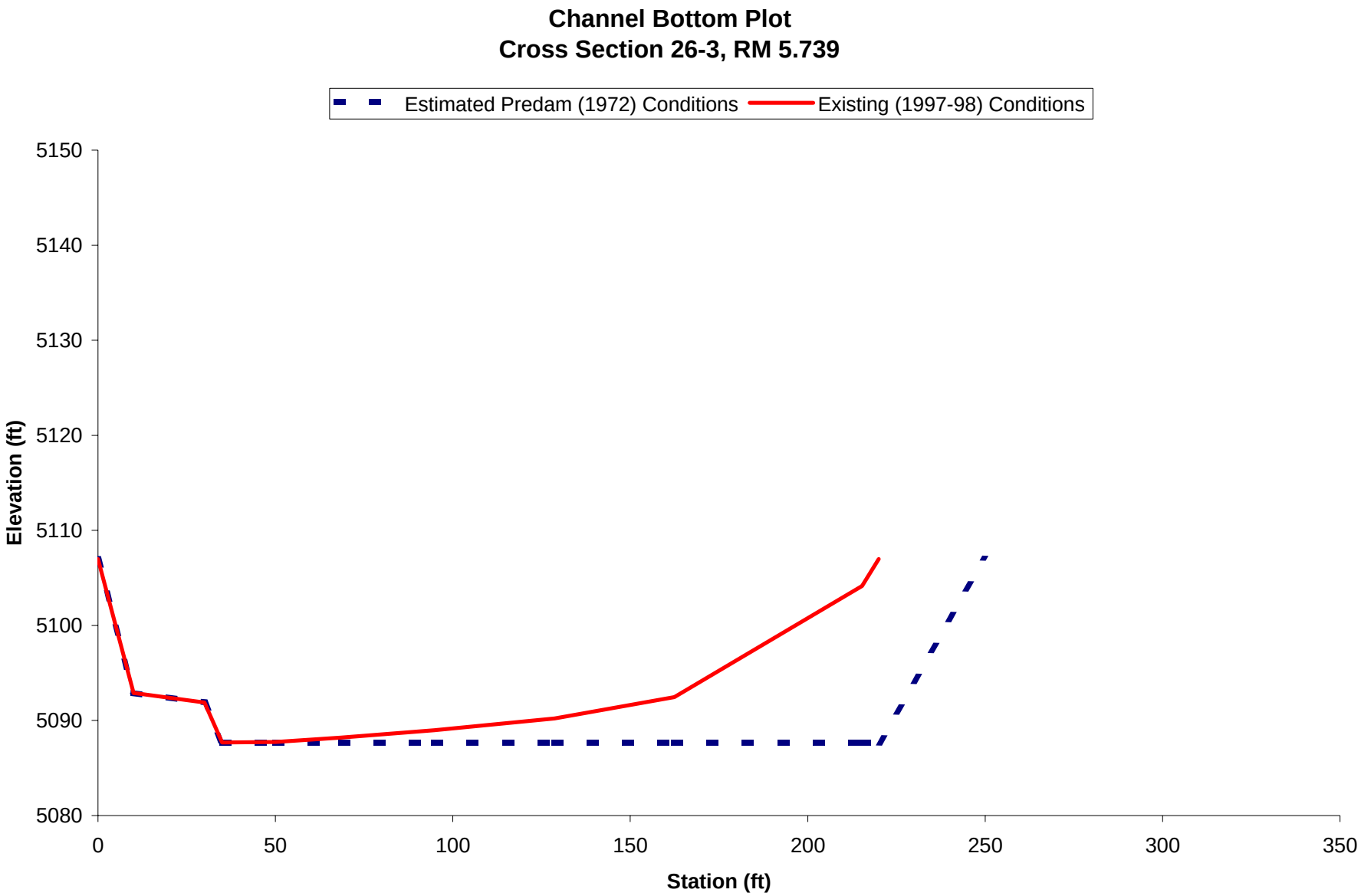

Channel Bottom Plot
Cross Section 25-7, RM 6.204
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

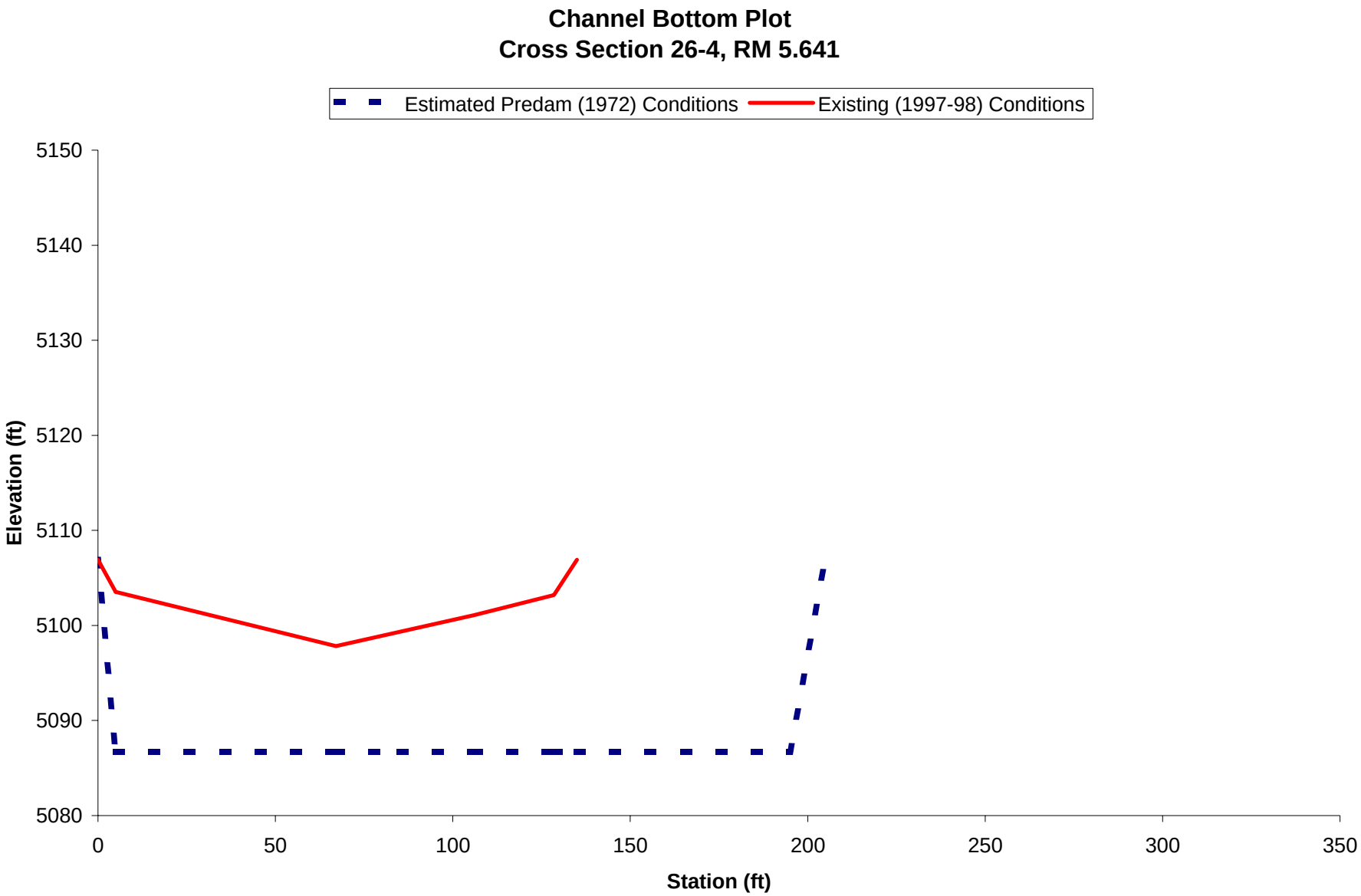

Channel Bottom Plot
Cross Section 25-8, RM 6.105
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

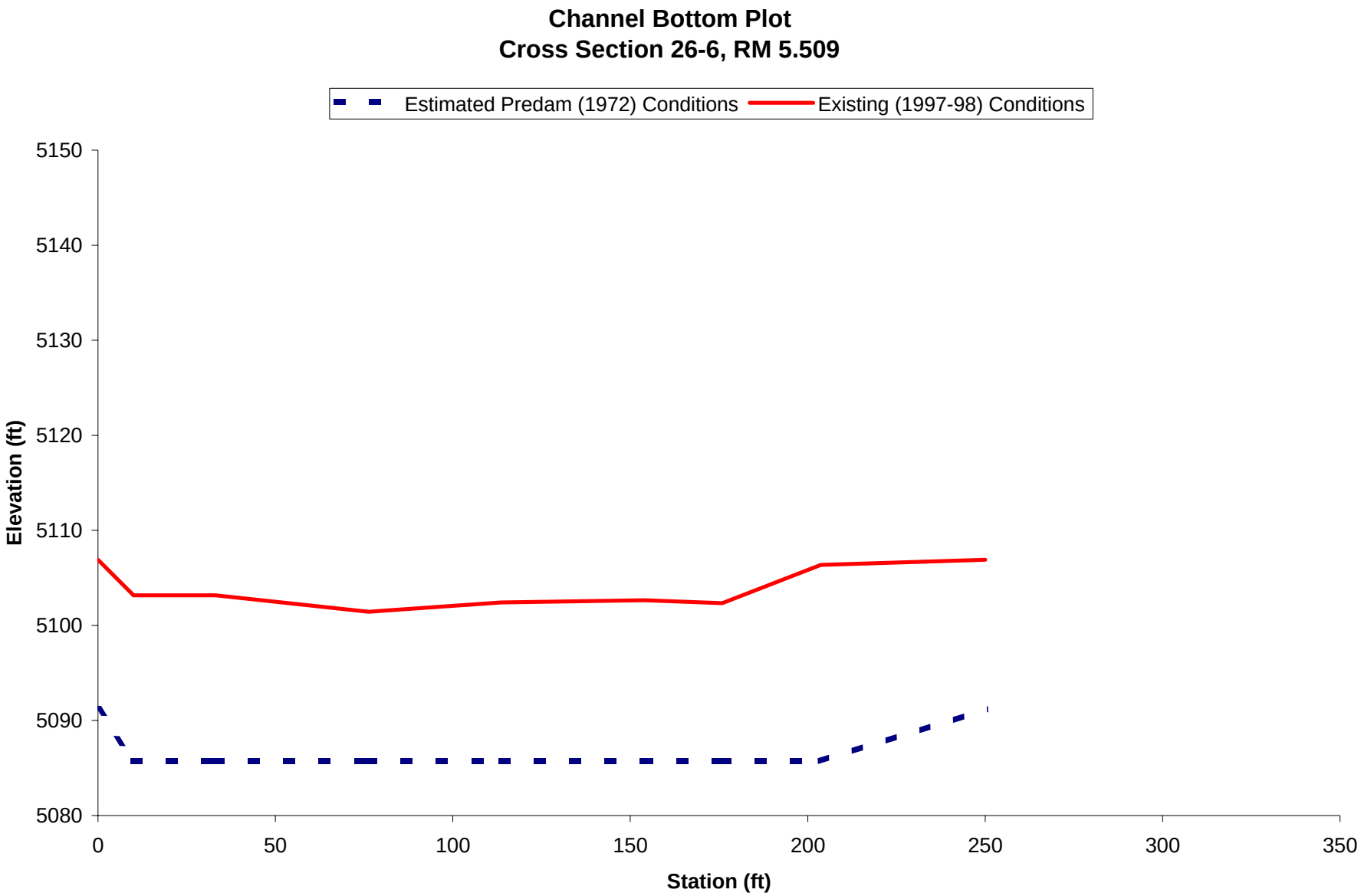

Channel Bottom Plot
Cross Section 25-9, RM 5.999
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

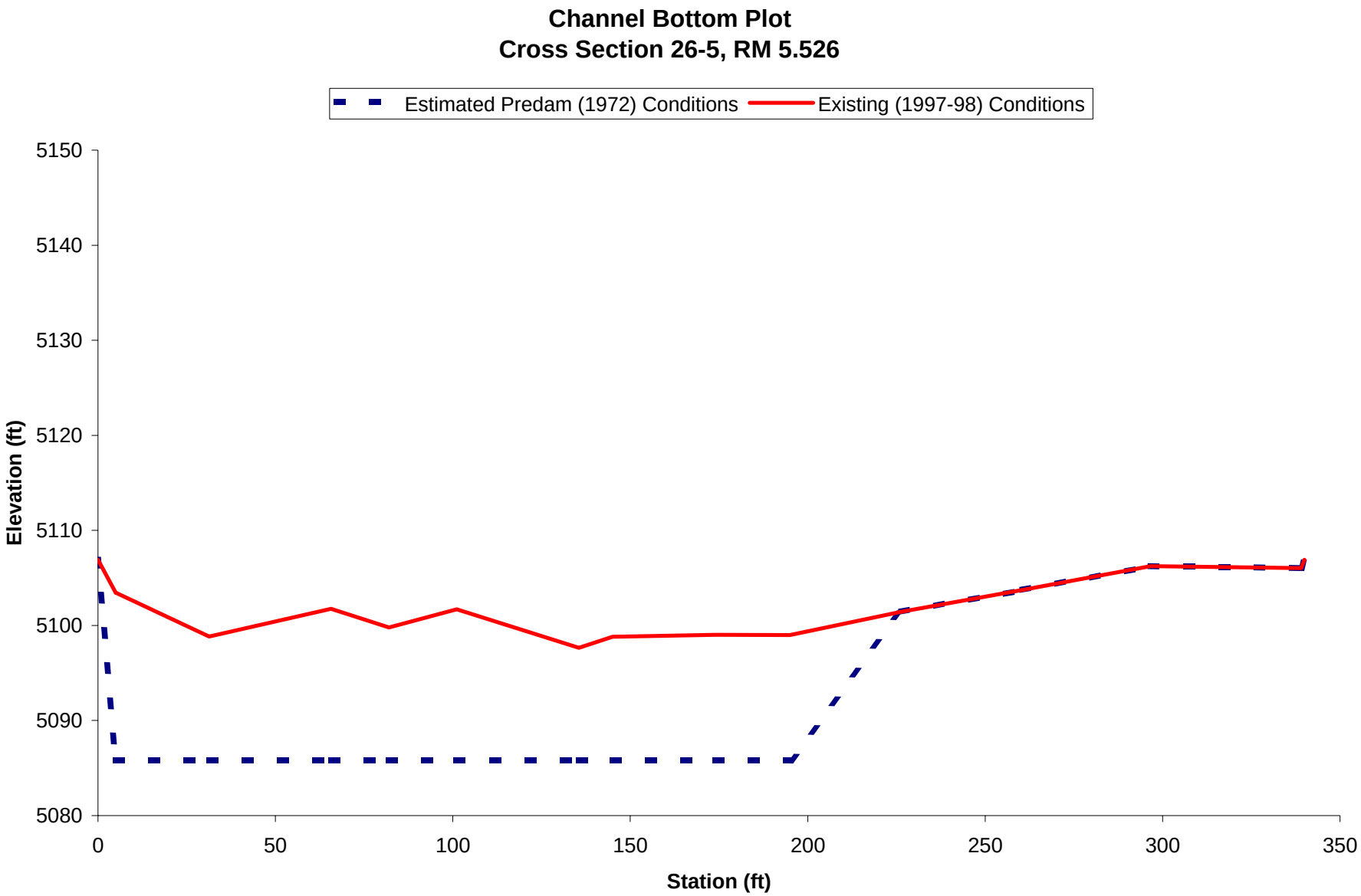

Channel Bottom Plot
Cross Section 26-1, RM 5.902
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

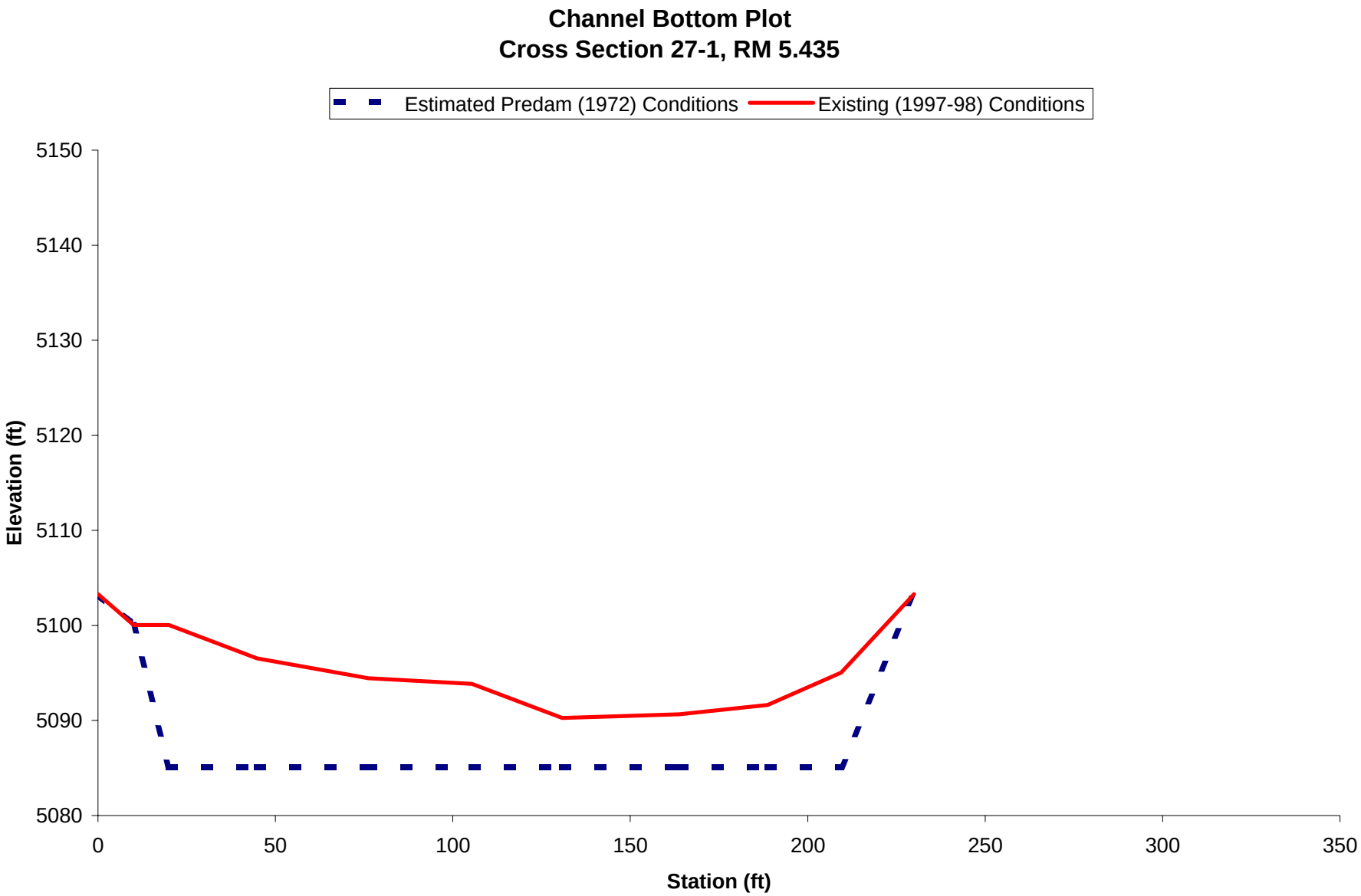

Channel Bottom Plot
Cross Section 26-2, RM 5.823
Existing (1997-98) Conditions
Estimated Predam (1972) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

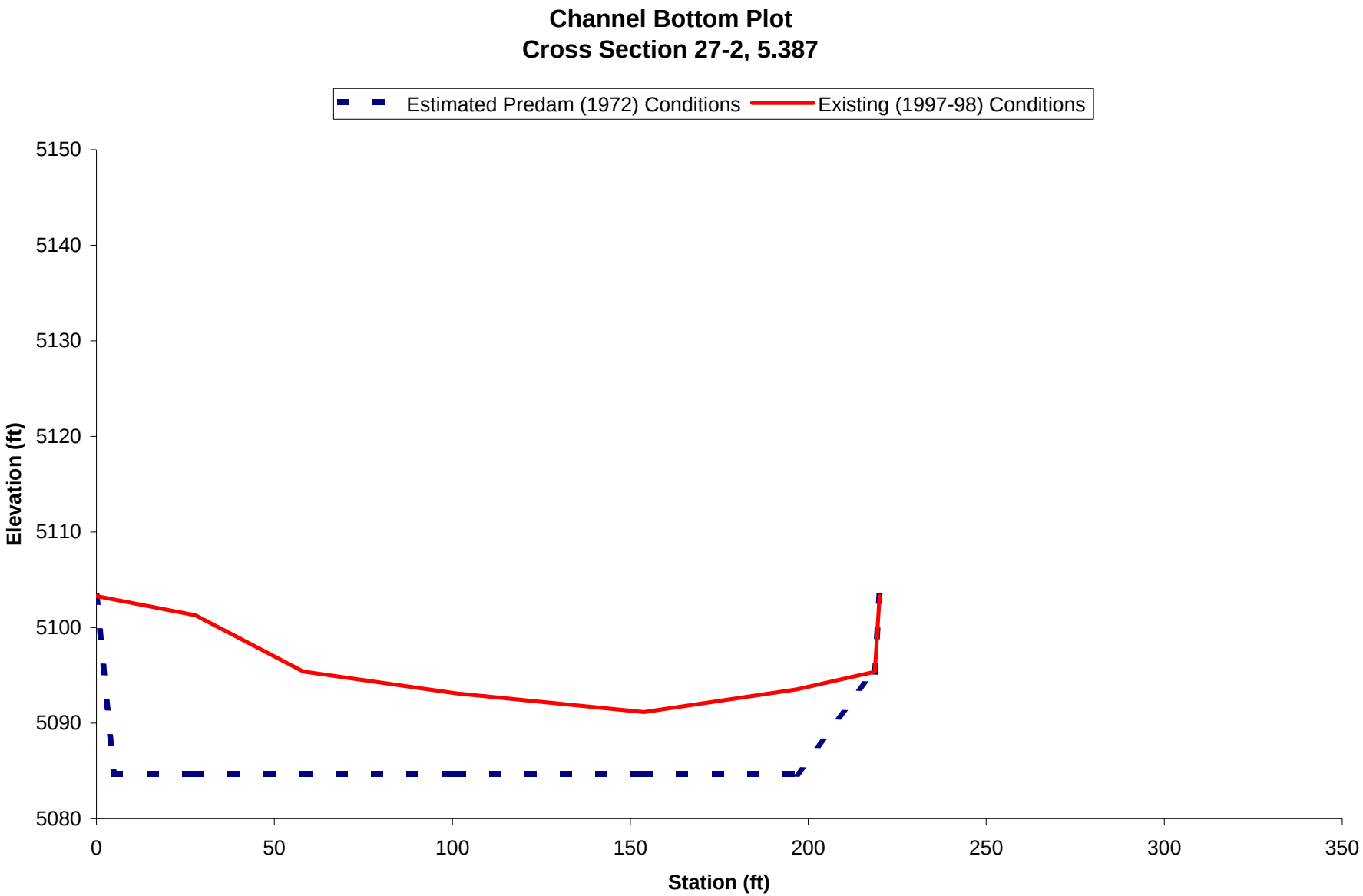

Channel Bottom Plot
Cross Section 26-3, RM 5.739
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

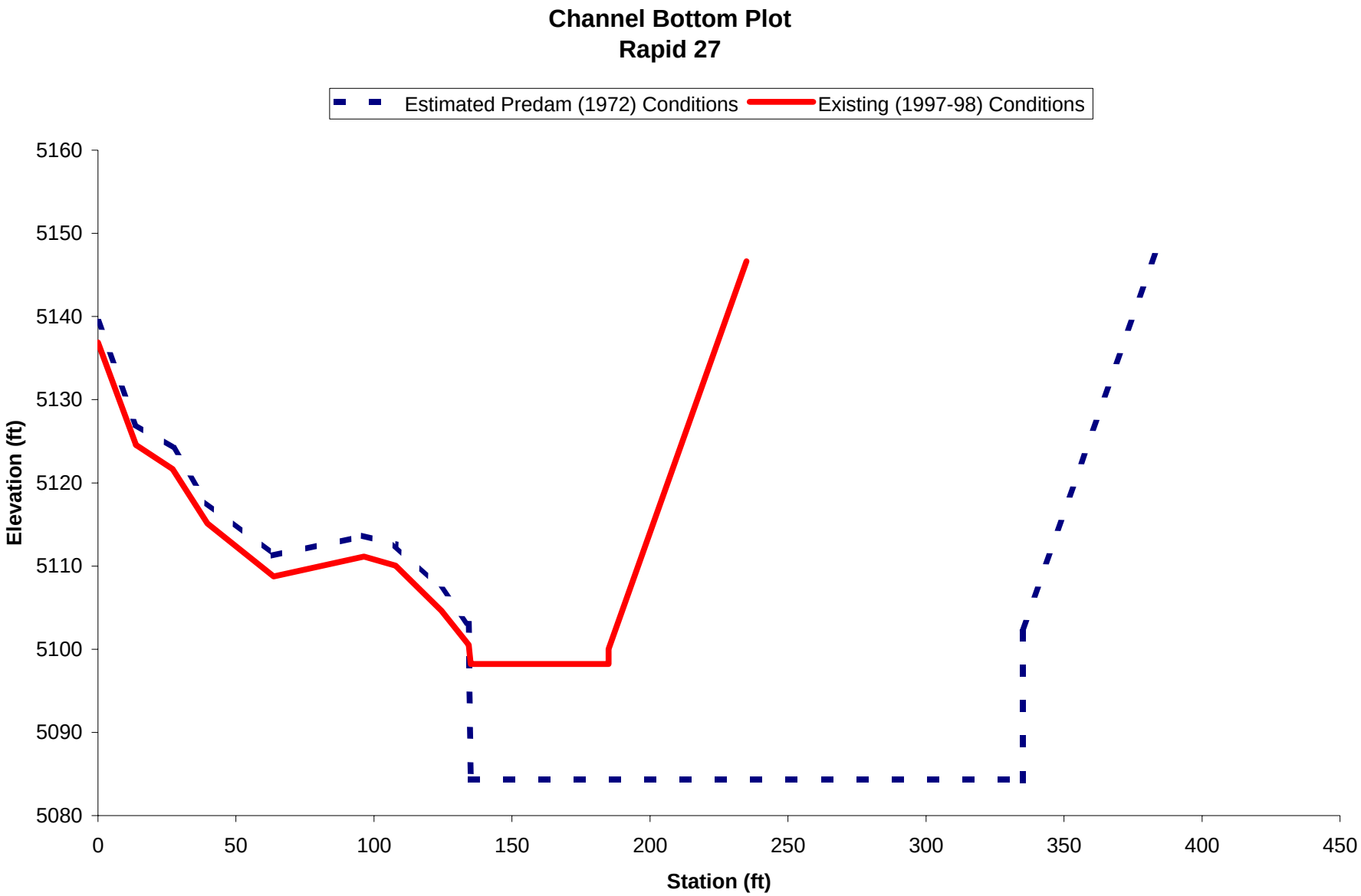

Channel Bottom Plot
Cross Section 26-4, RM 5.641
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

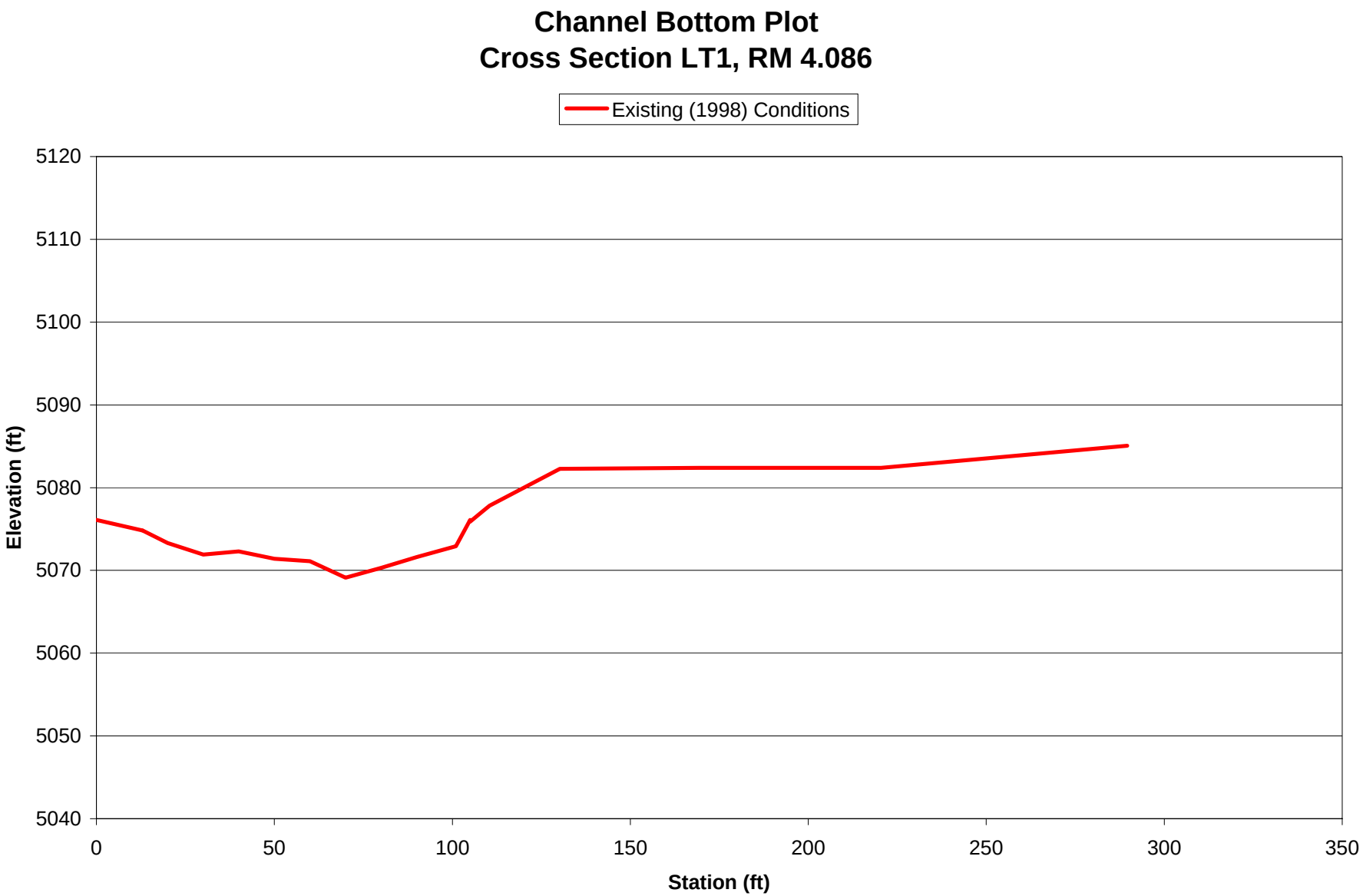

Channel Bottom Plot
Cross Section 26-6, RM 5.509
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

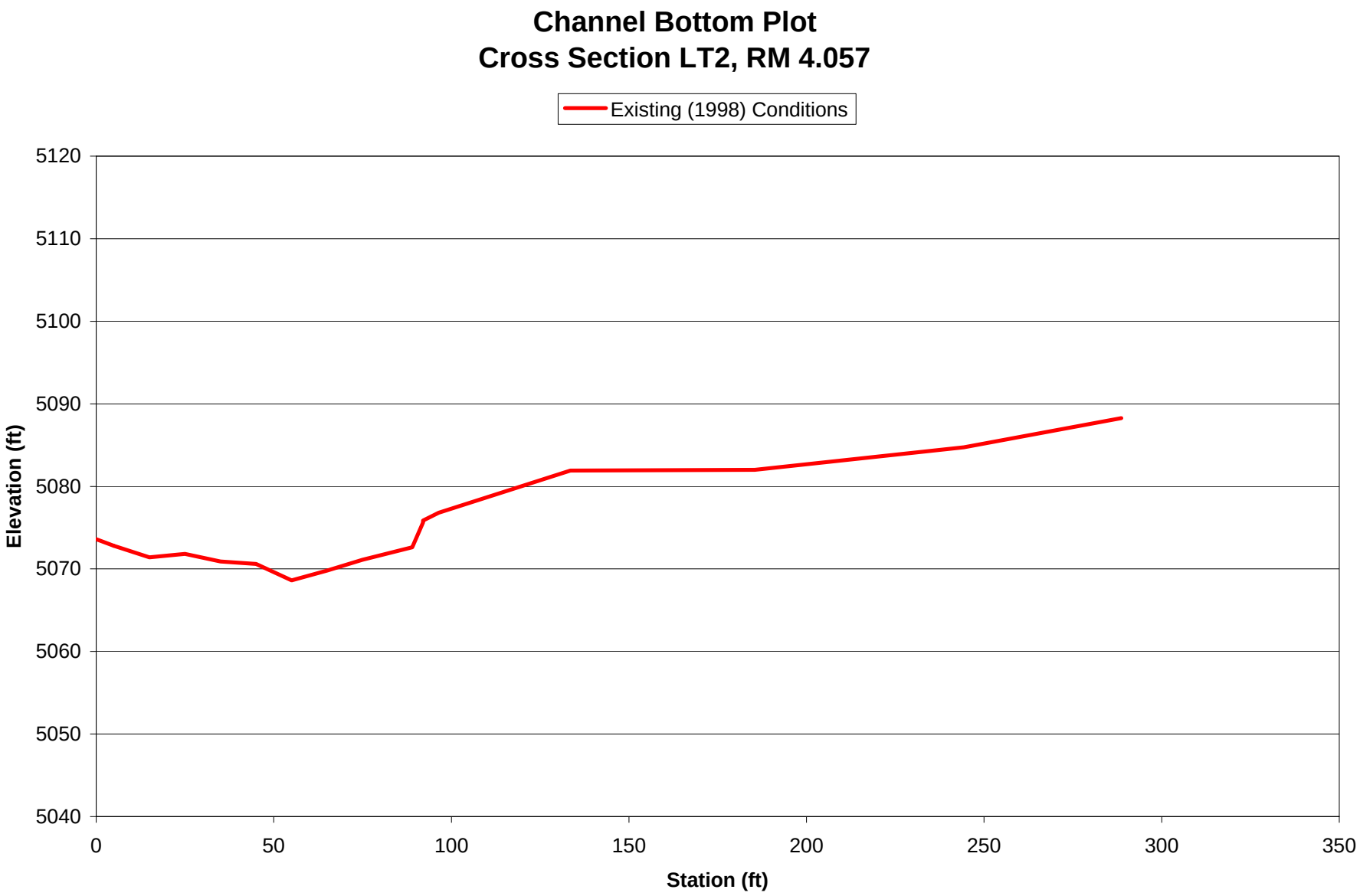

Channel Bottom Plot
Cross Section 26-5, RM 5.526
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

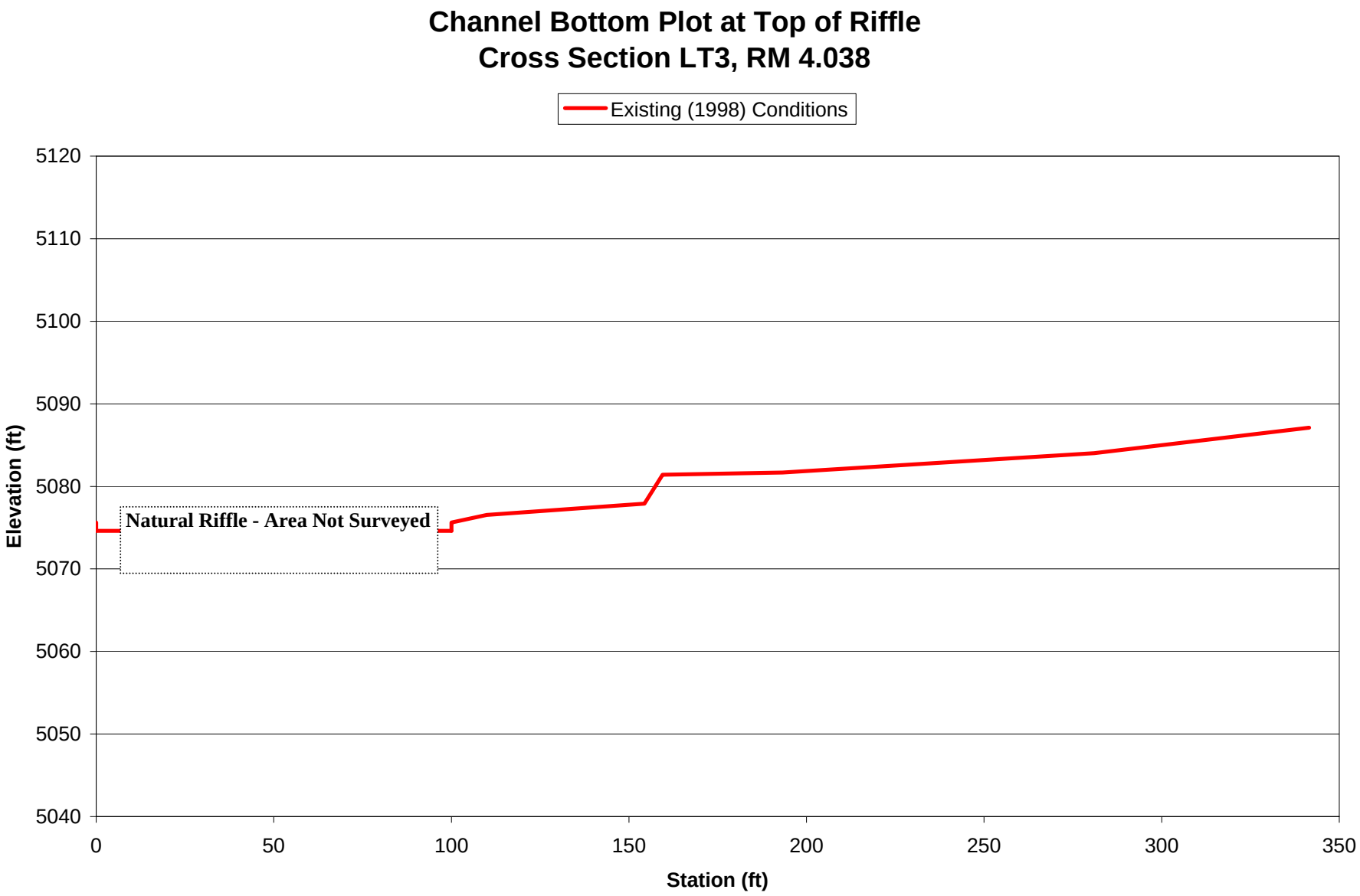

Channel Bottom Plot
Cross Section 27-1, RM 5.435
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

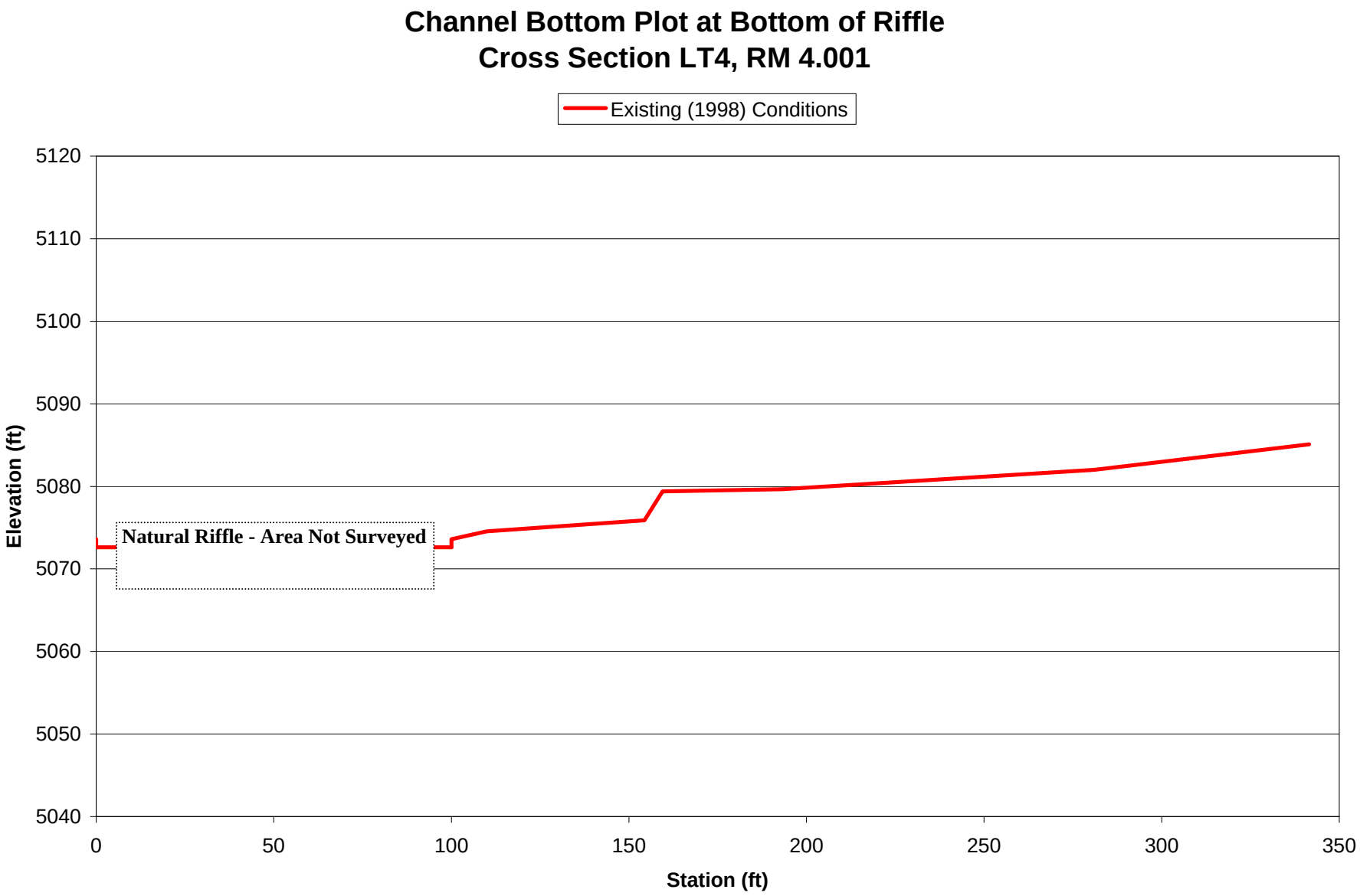

Channel Bottom Plot
Cross Section 27-2, 5.387
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
Station (ft)

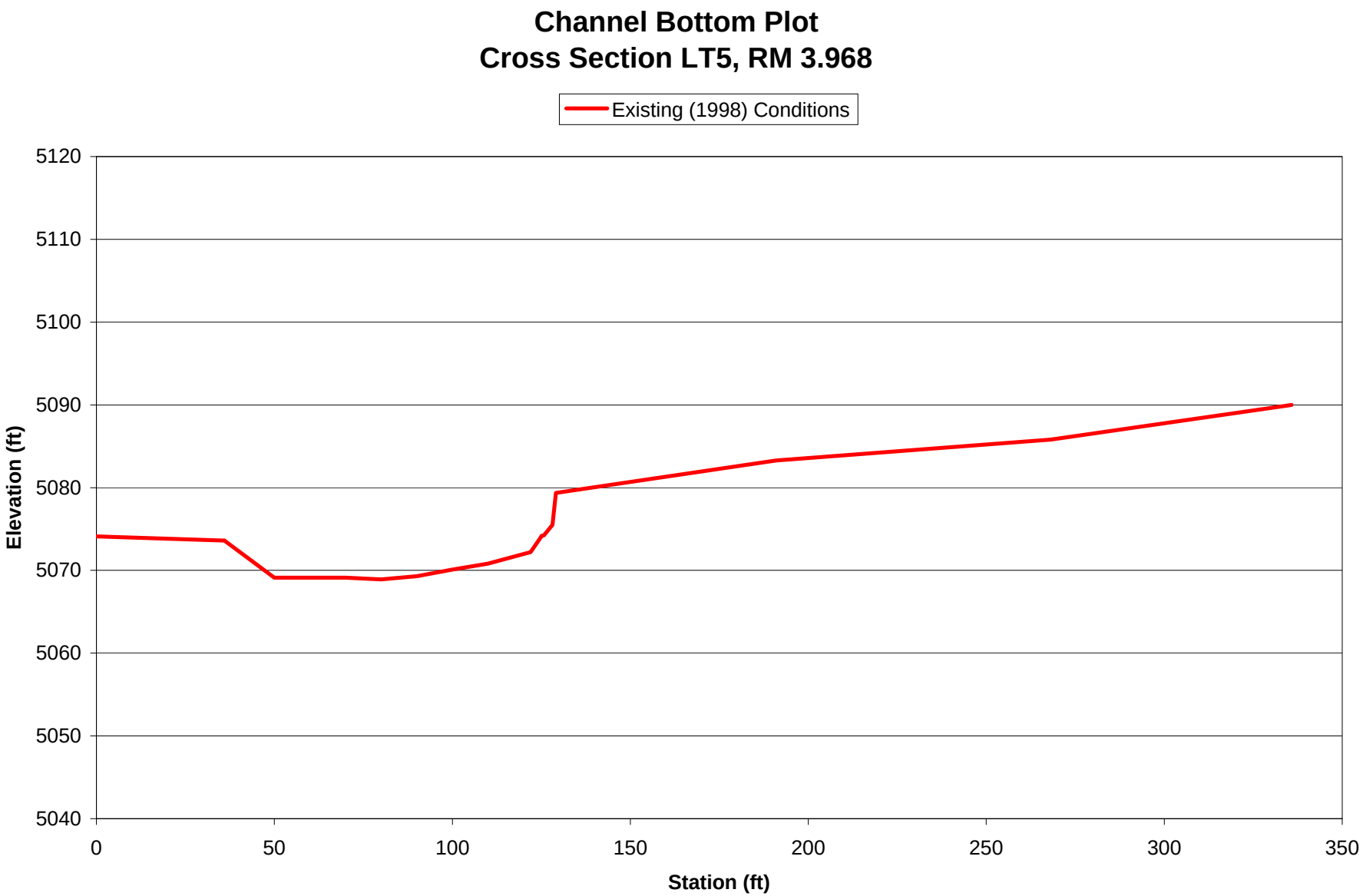

Channel Bottom Plot
Rapid 27
Estimated Predam (1972) Conditions
Existing (1997-98) Conditions
Elevation (ft)
5160
5150
5140
5130
5120
5110
5100
5090
5080
0
50
100
150
200
250
300
350
400
450
Station (ft)

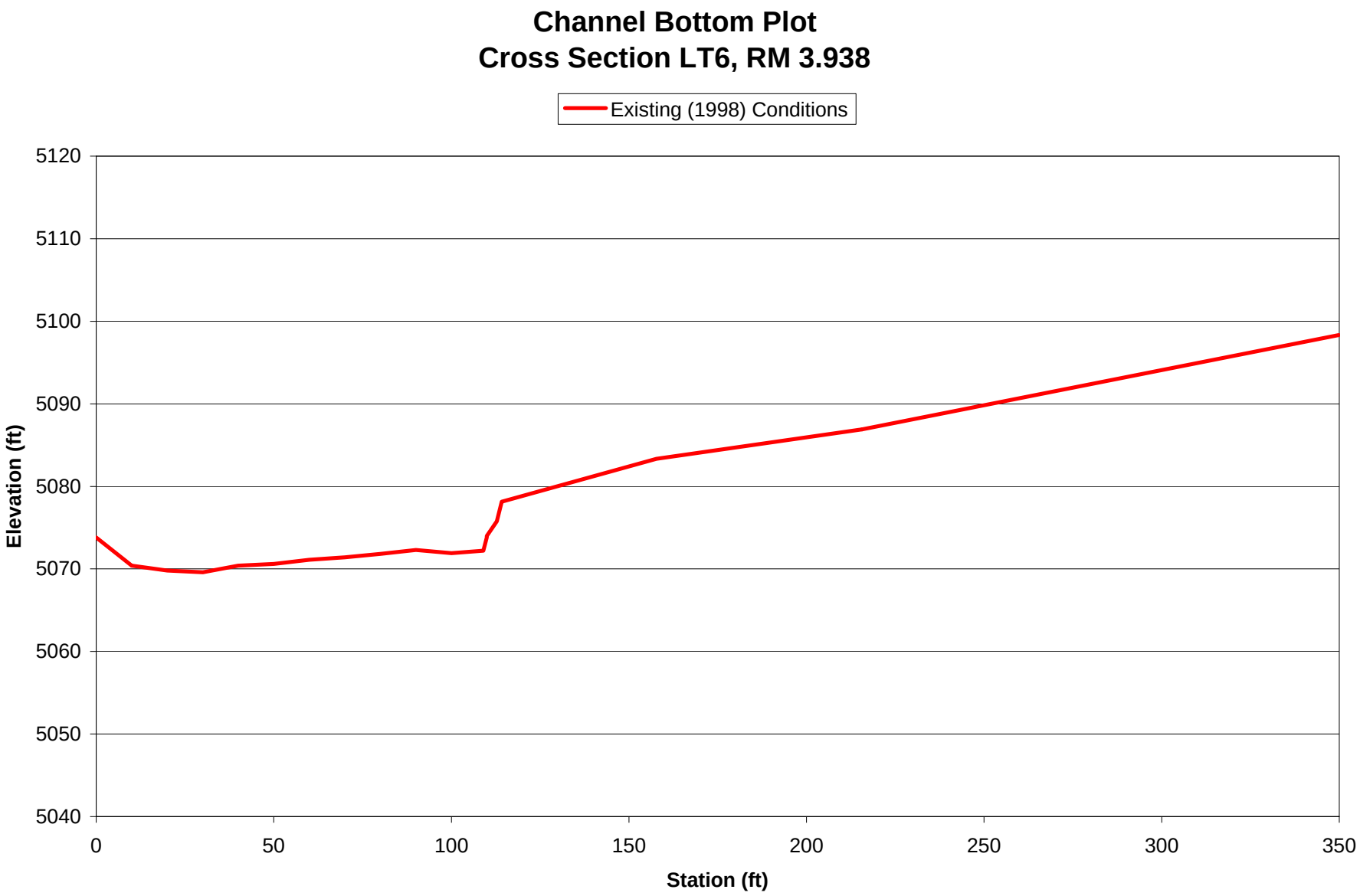

Channel Bottom Plot
Cross Section LT1, RM 4.086
Existing (1998) Conditions
Elevation (ft)
5120
5110
5100
5090
5080
5070
5060
5050
5040
0
50
100
150
200
250
300
350
Station (ft)

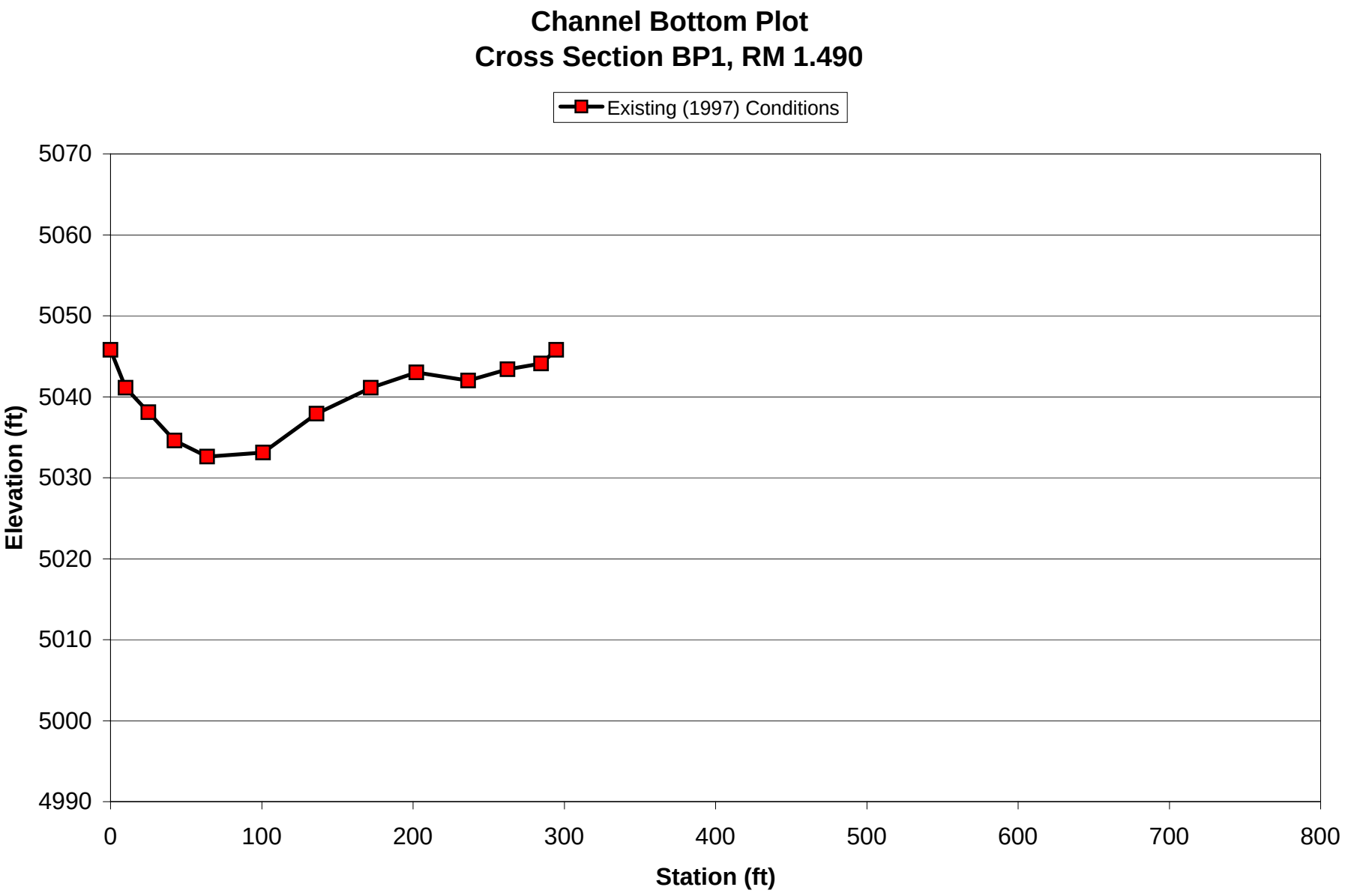

Channel Bottom Plot
Cross Section LT2, RM 4.057
Existing (1998) Conditions
Elevation (ft)
5120
5110
5100
5090
5080
5070
5060
5050
5040
0
50
100
150
200
250
300
350
Station (ft)

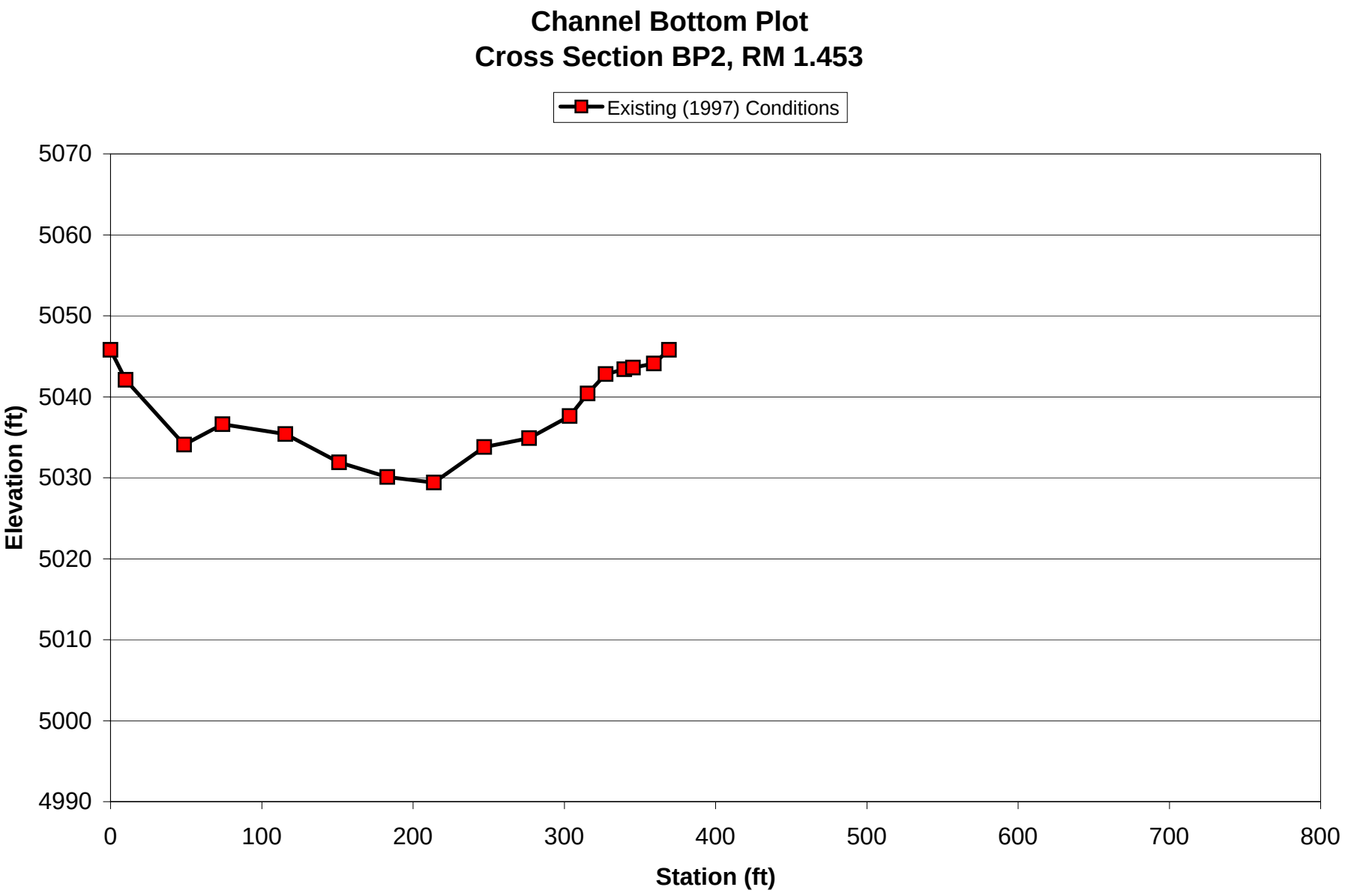

Channel Bottom Plot at Top of Riffle
Cross Section LT3, RM 4.038
Existing (1998) Conditions
Natural Riffle - Area Not Surveyed
Elevation (ft)
5120
5110
5100
5090
5080
5070
5060
5050
5040
0
50
100
150
200
250
300
350
Station (ft)

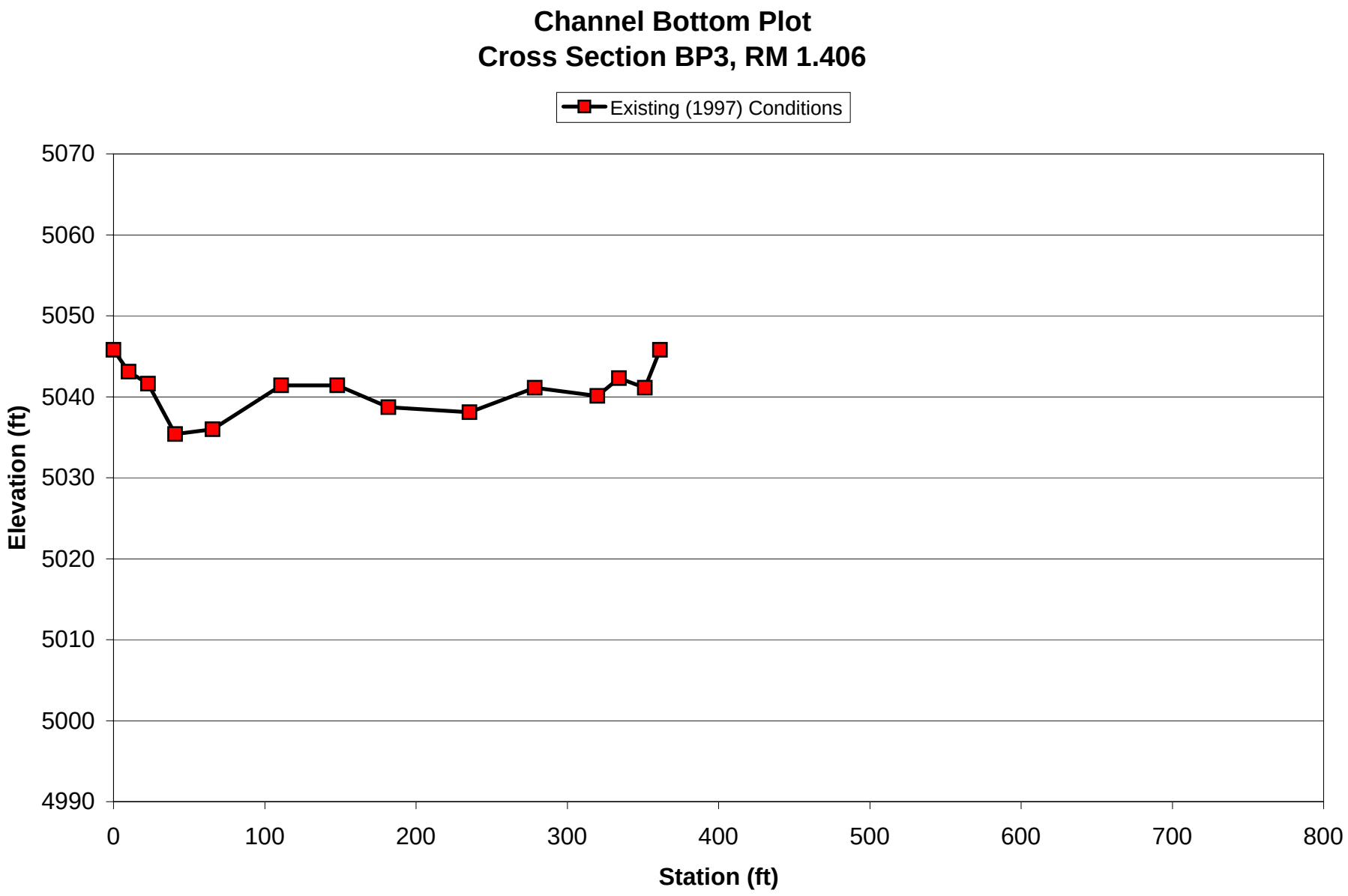

Channel Bottom Plot at Bottom of Riffle
Cross Section LT4, RM 4.001
Existing (1998) Conditions
Natural Riffle - Area Not Surveyed
Elevation (ft)
5120
5110
5100
5090
5080
5070
5060
5050
5040
0
50
100
150
200
250
300
350
Station (ft)

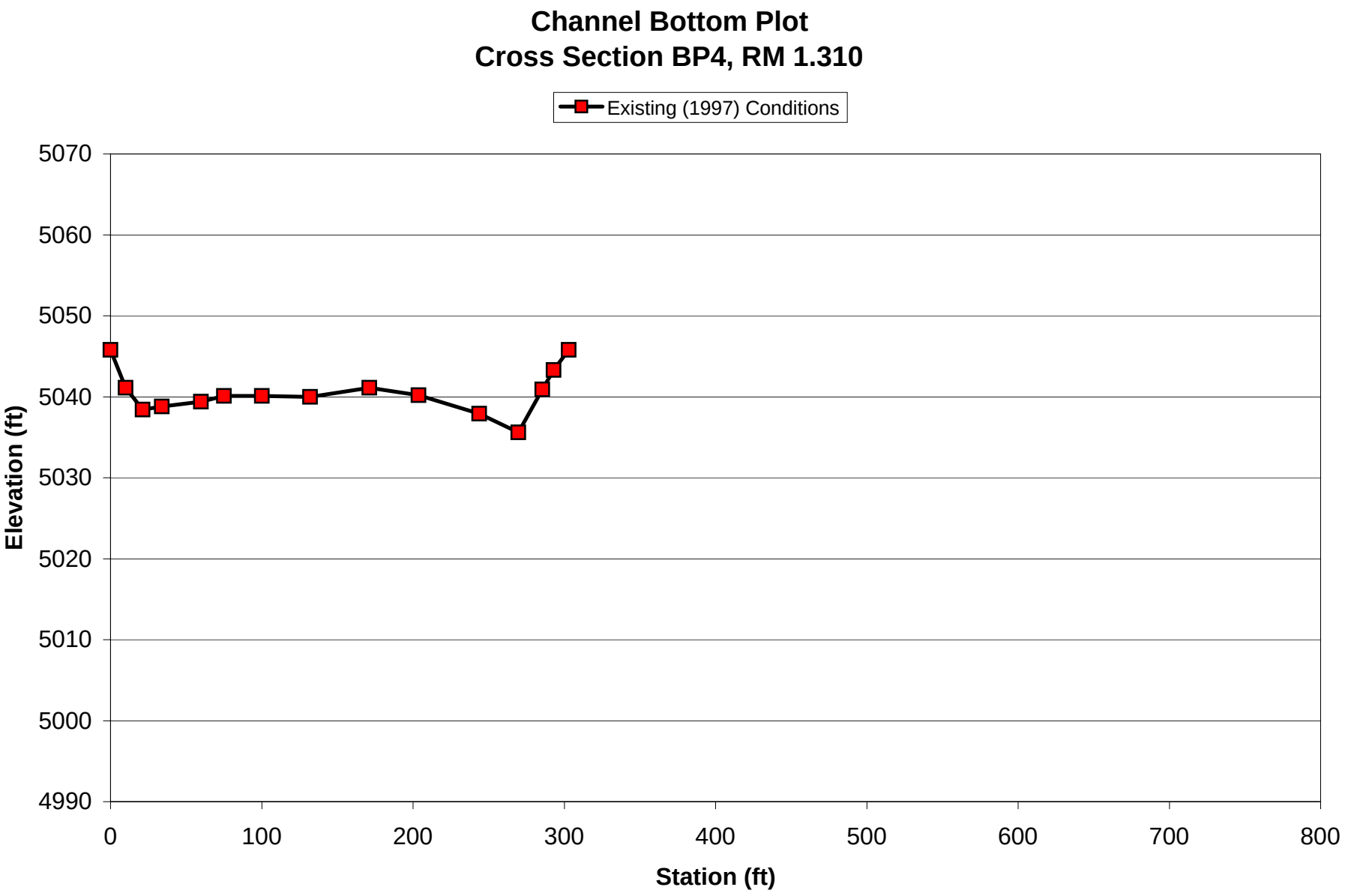

Channel Bottom Plot
Cross Section LT5, RM 3.968
Existing (1998) Conditions
Elevation (ft)
5120
5110
5100
5090
5080
5070
5060
5050
5040
0
50
100
150
200
250
300
350
Station (ft)

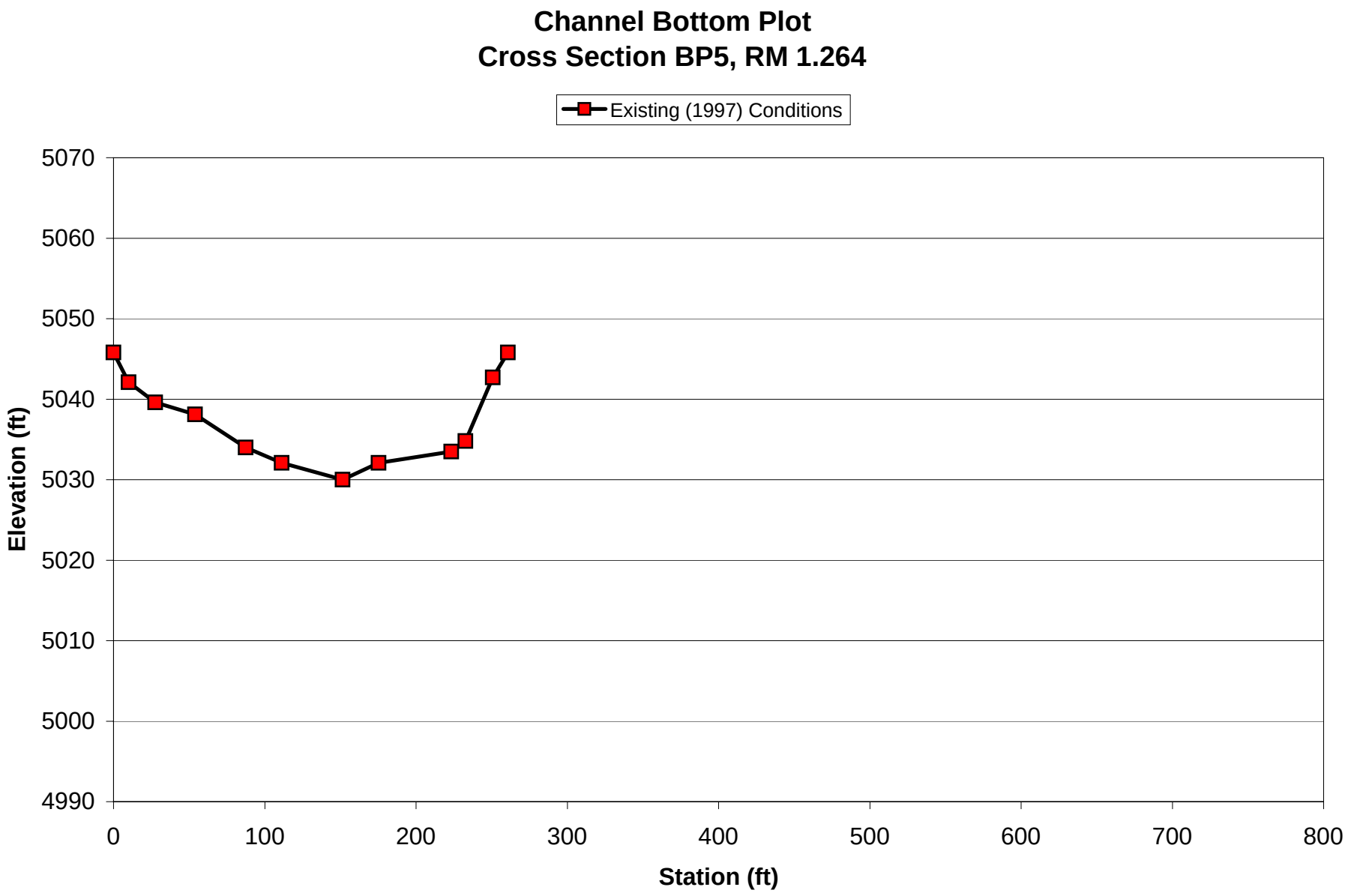

Channel Bottom Plot
Cross Section LT6, RM 3.938
Existing (1998) Conditions
5120
5110
5100
5090
5080
5070
5060
5050
5040
Elevation (ft)
0
50
100
150
200
250
300
350
Station (ft)

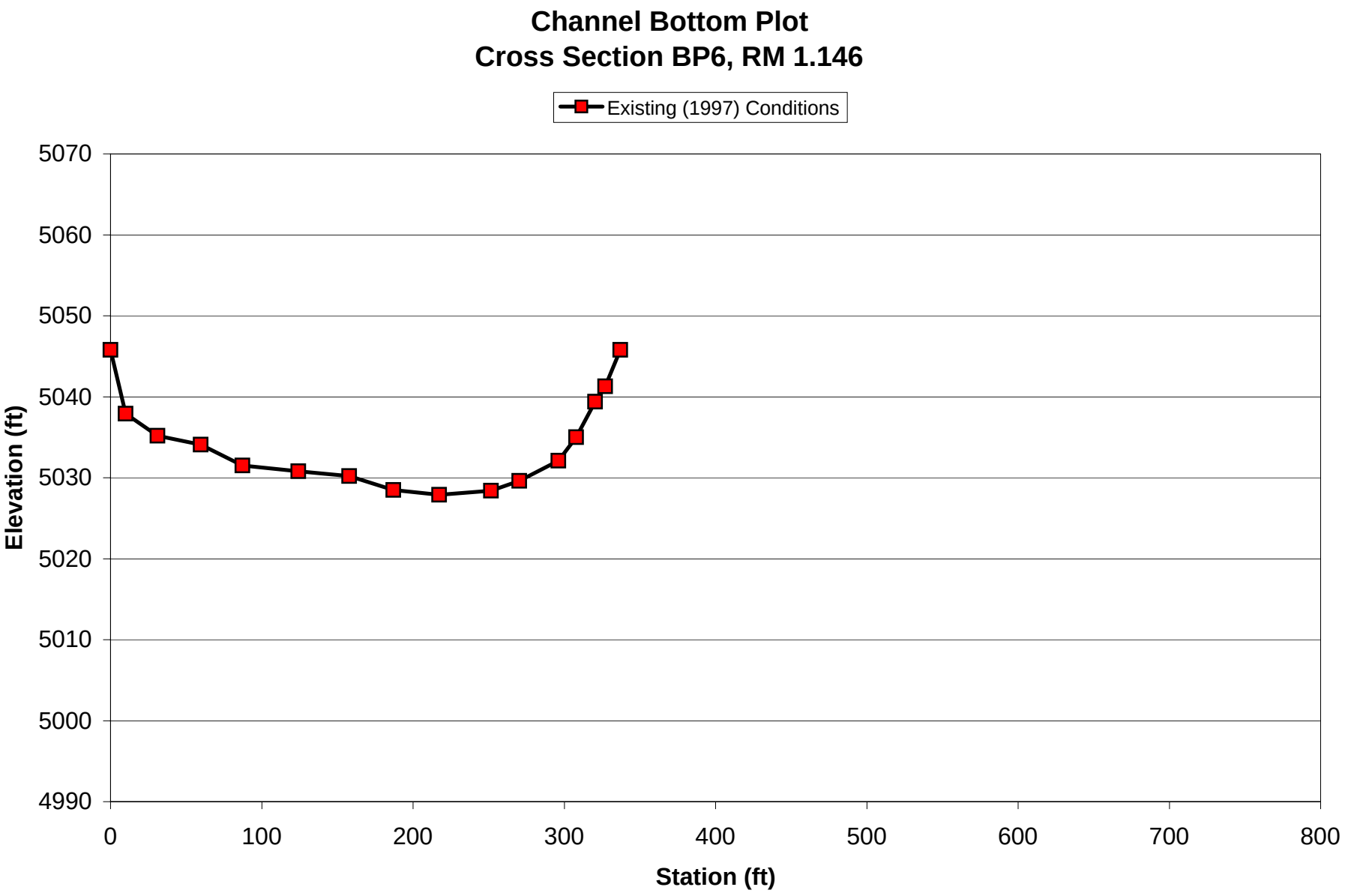

Channel Bottom Plot
Cross Section BP1, RM 1.490
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

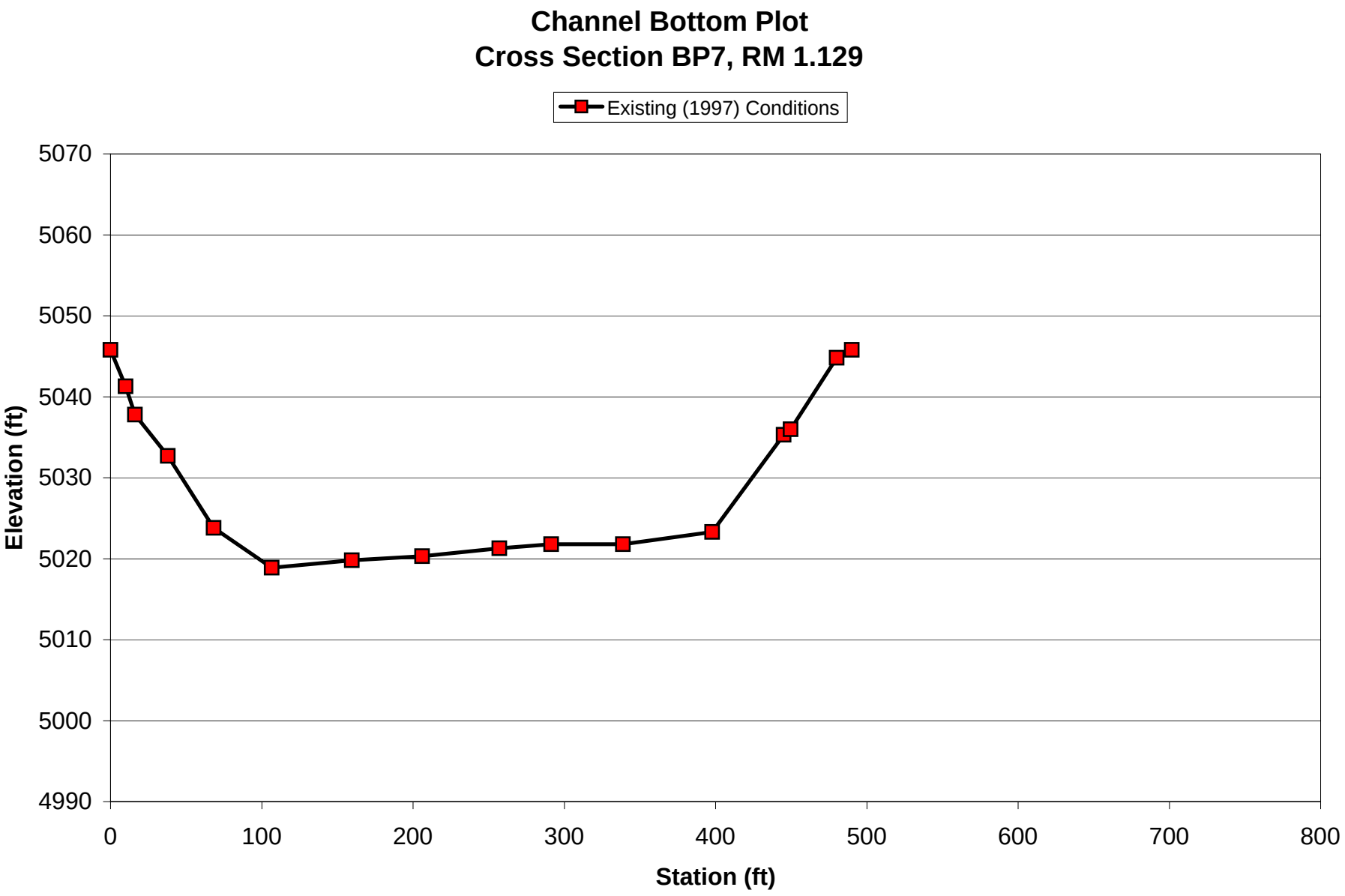

Channel Bottom Plot
Cross Section BP2, RM 1.453
Existing (1997) Conditions
5070
5060
5050
5040
5030
5020
5010
5000
4990
Elevation (ft)
0
100
200
300
400
500
600
700
800
Station (ft)

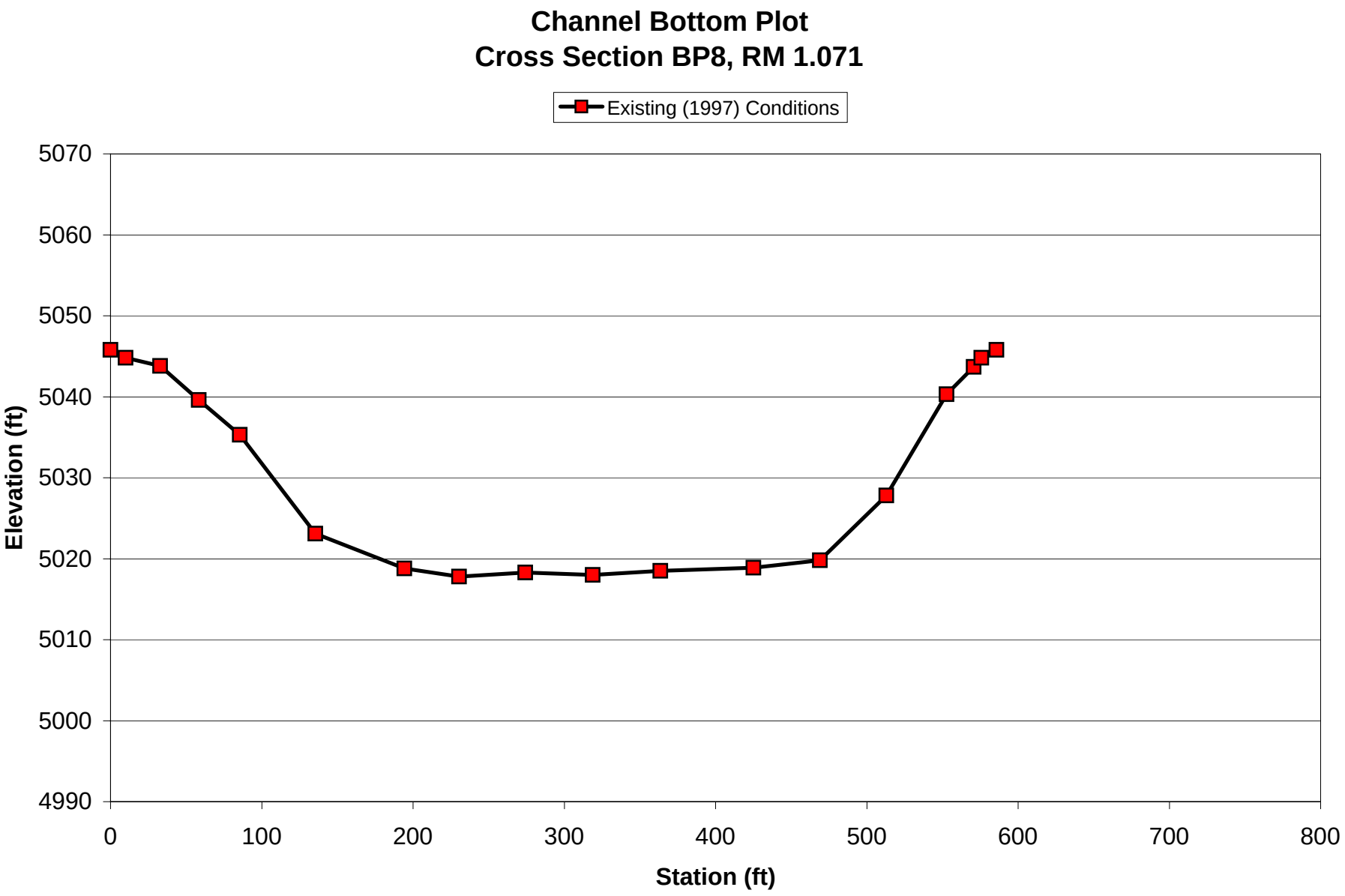

Channel Bottom Plot
Cross Section BP3, RM 1.406
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

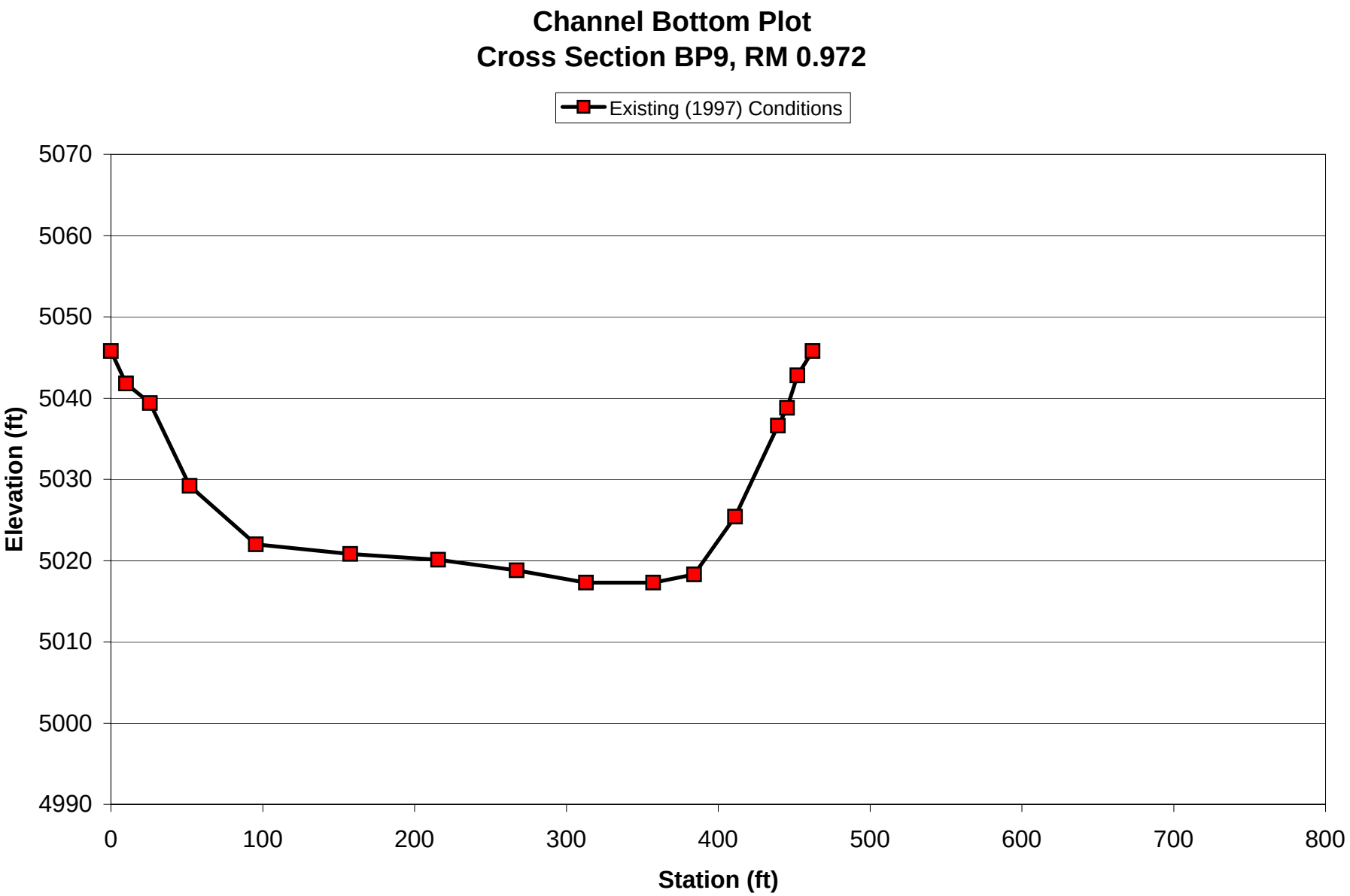

Channel Bottom Plot
Cross Section BP4, RM 1.310
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

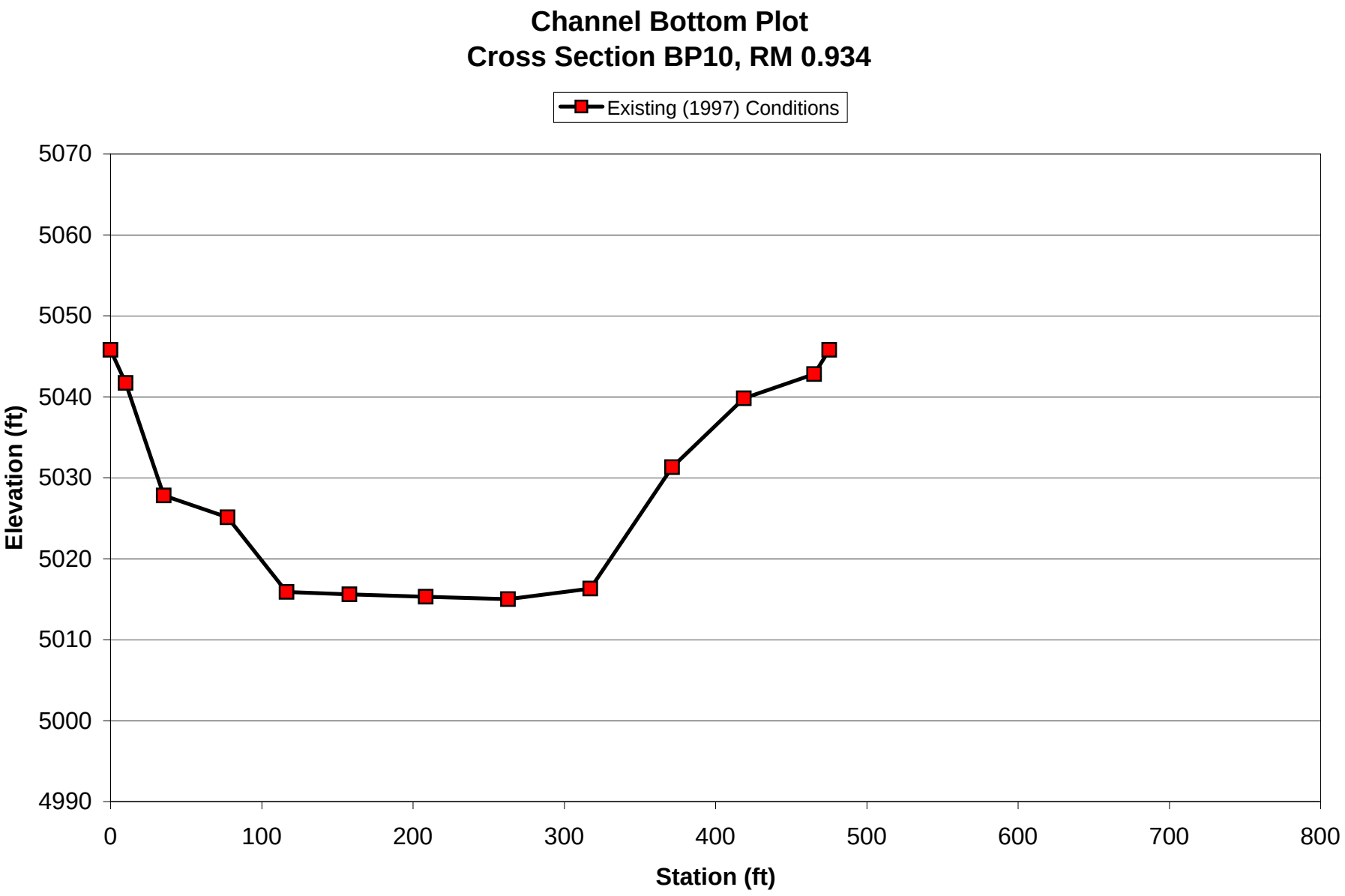

Channel Bottom Plot
Cross Section BP5, RM 1.264
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

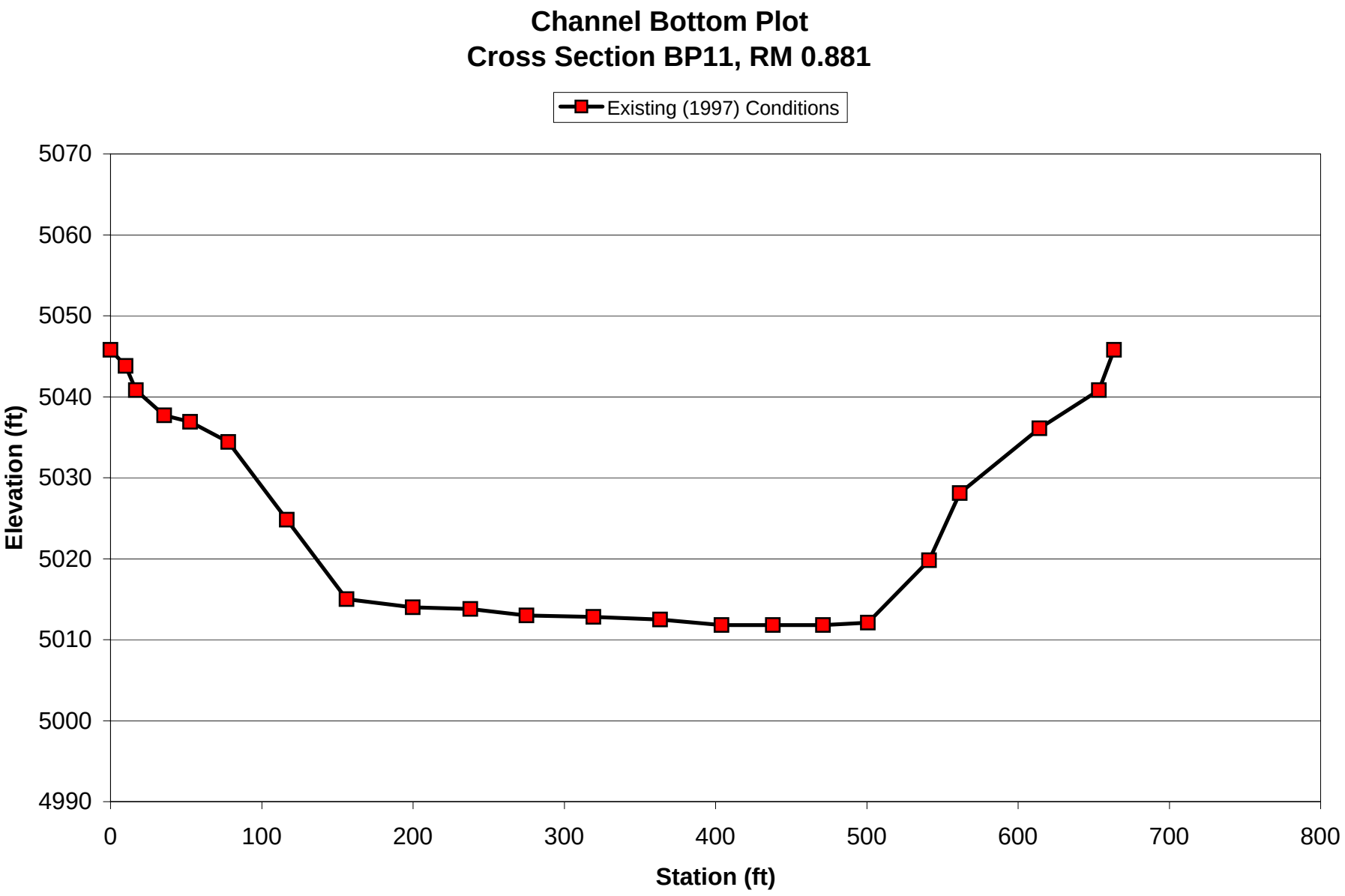

Channel Bottom Plot
Cross Section BP6, RM 1.146
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

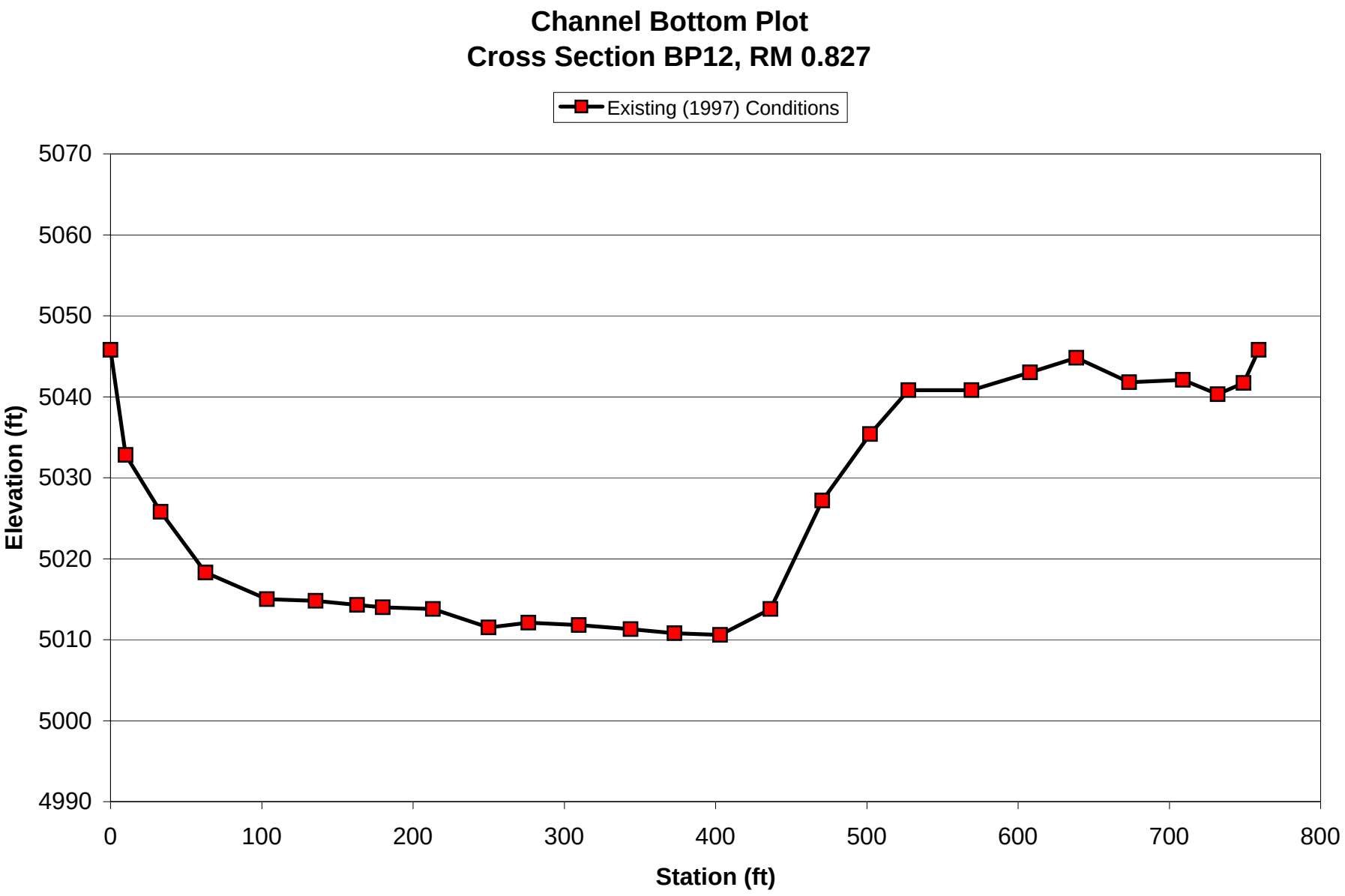

Channel Bottom Plot
Cross Section BP7, RM 1.129
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

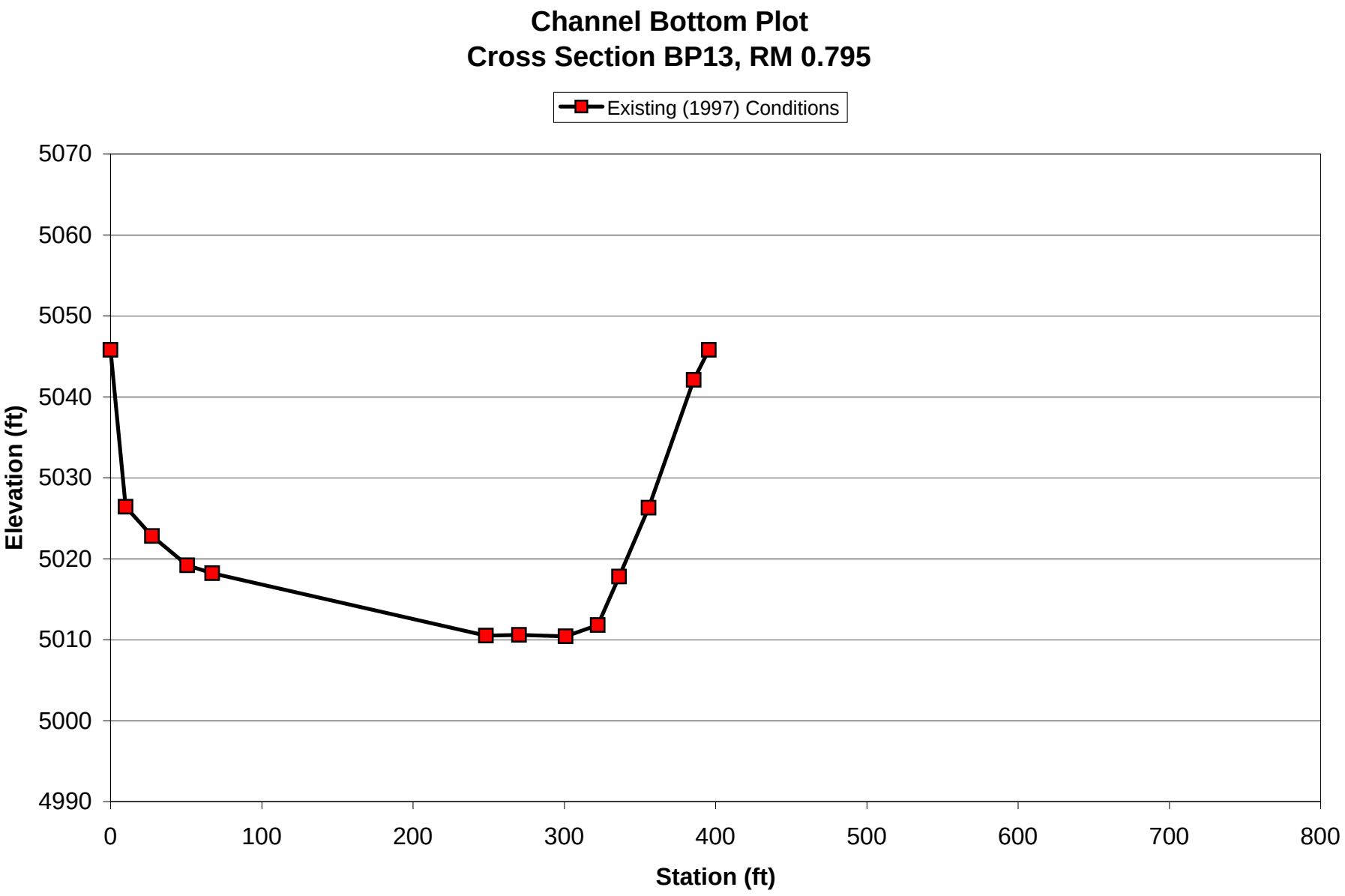

Channel Bottom Plot
Cross Section BP8, RM 1.071
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

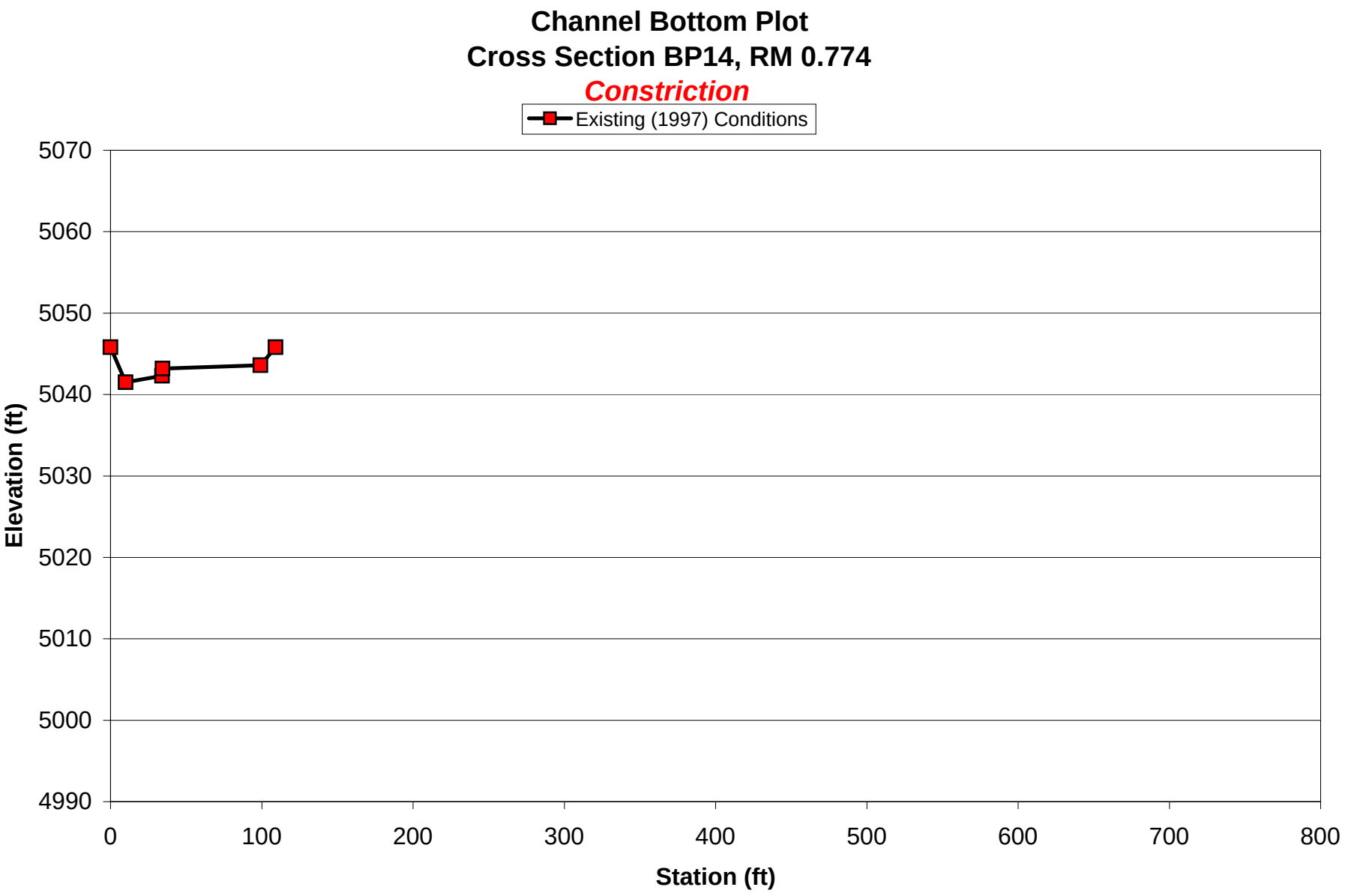

Channel Bottom Plot
Cross Section BP9, RM 0.972
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

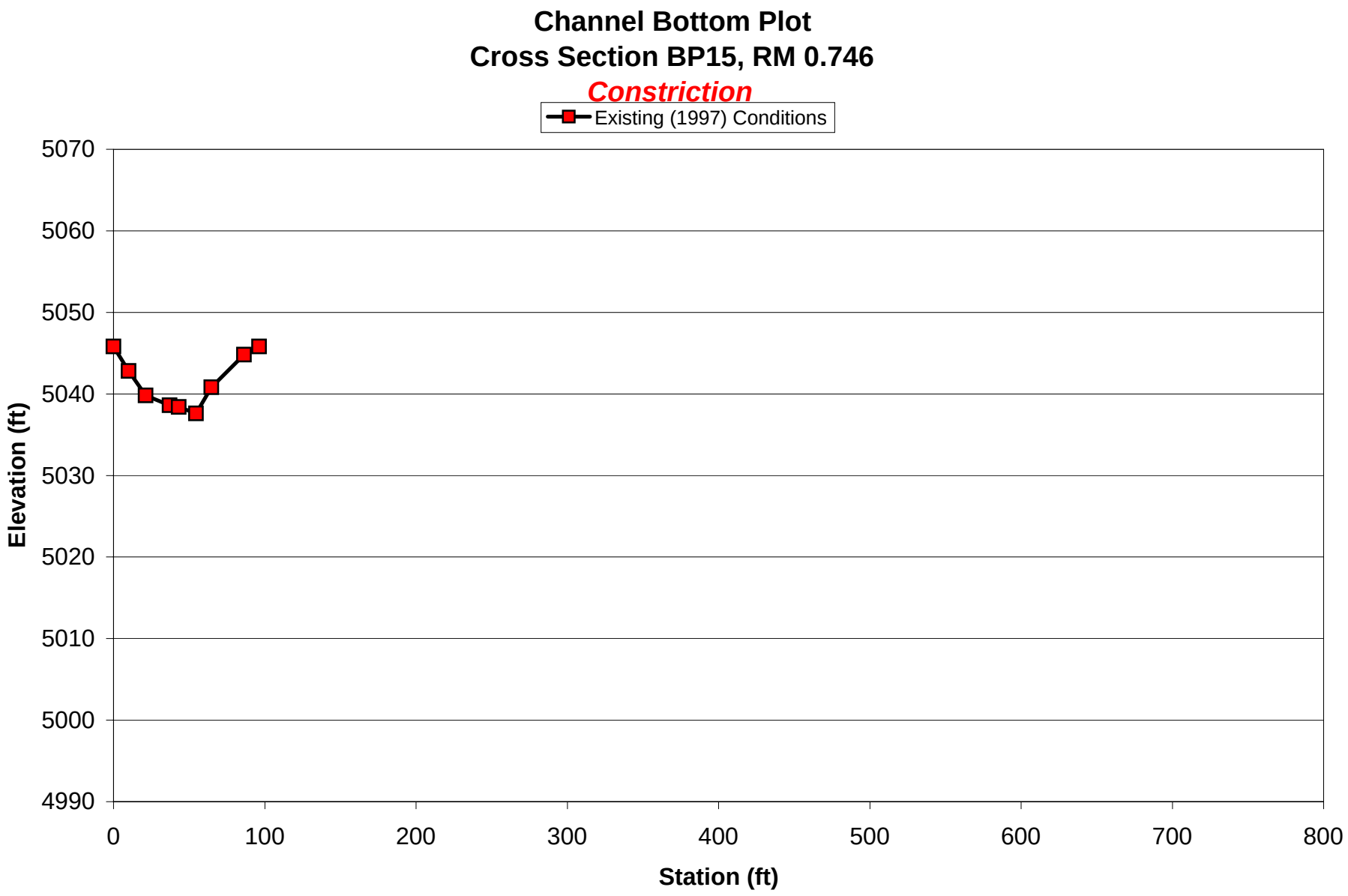

Channel Bottom Plot
Cross Section BP10, RM 0.934
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

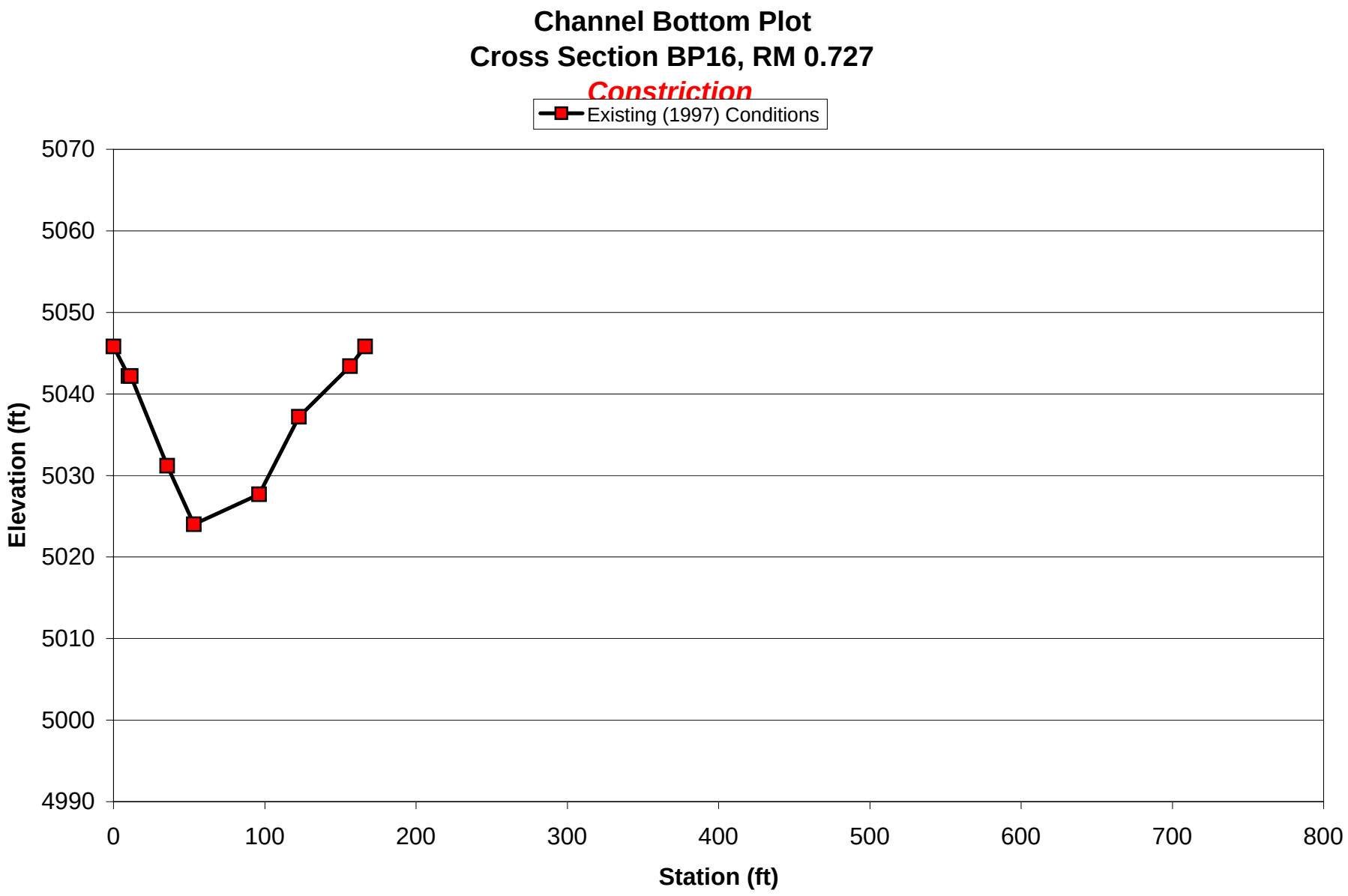

Channel Bottom Plot
Cross Section BP11, RM 0.881
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

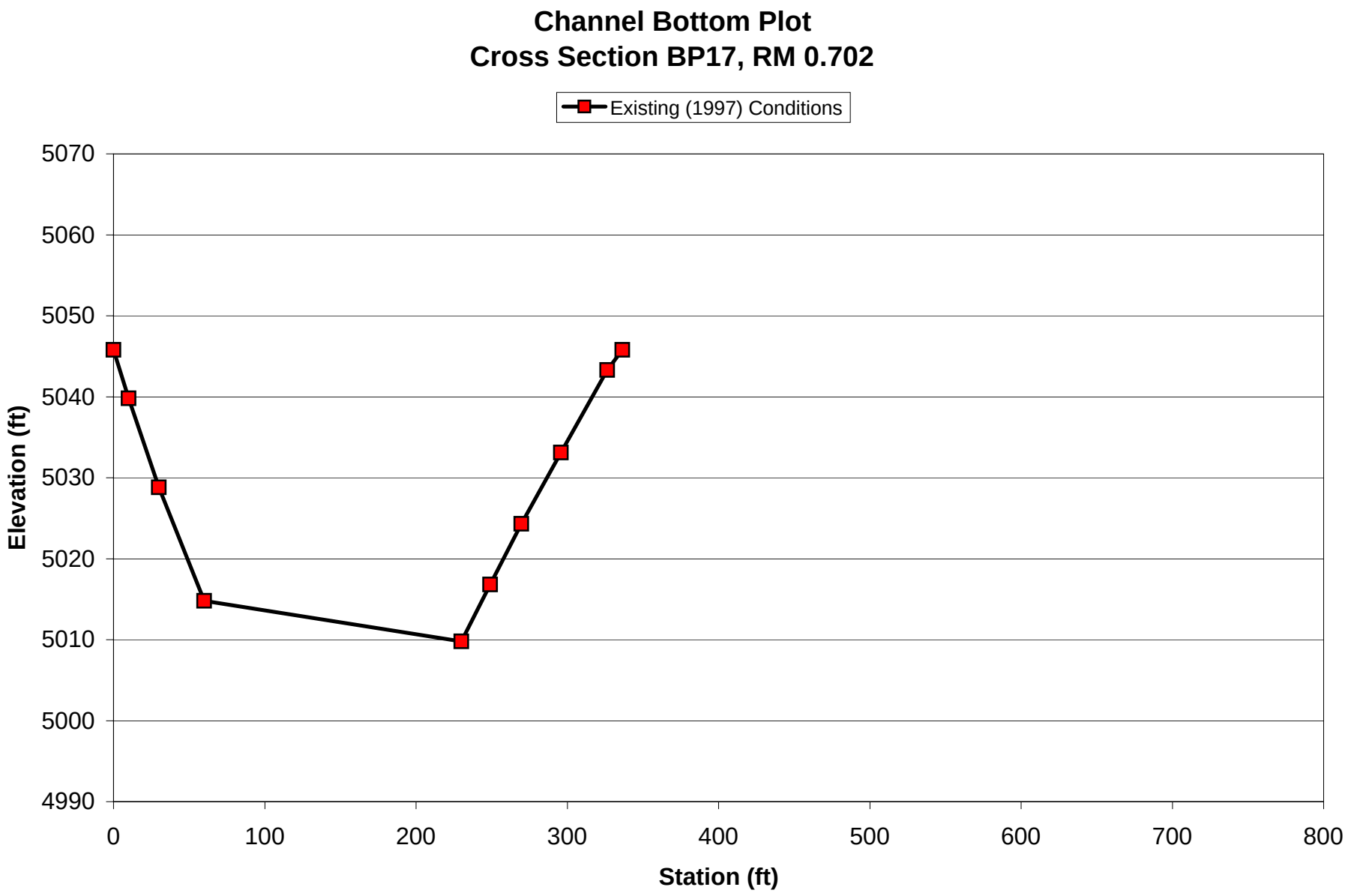

Channel Bottom Plot
Cross Section BP12, RM 0.827
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

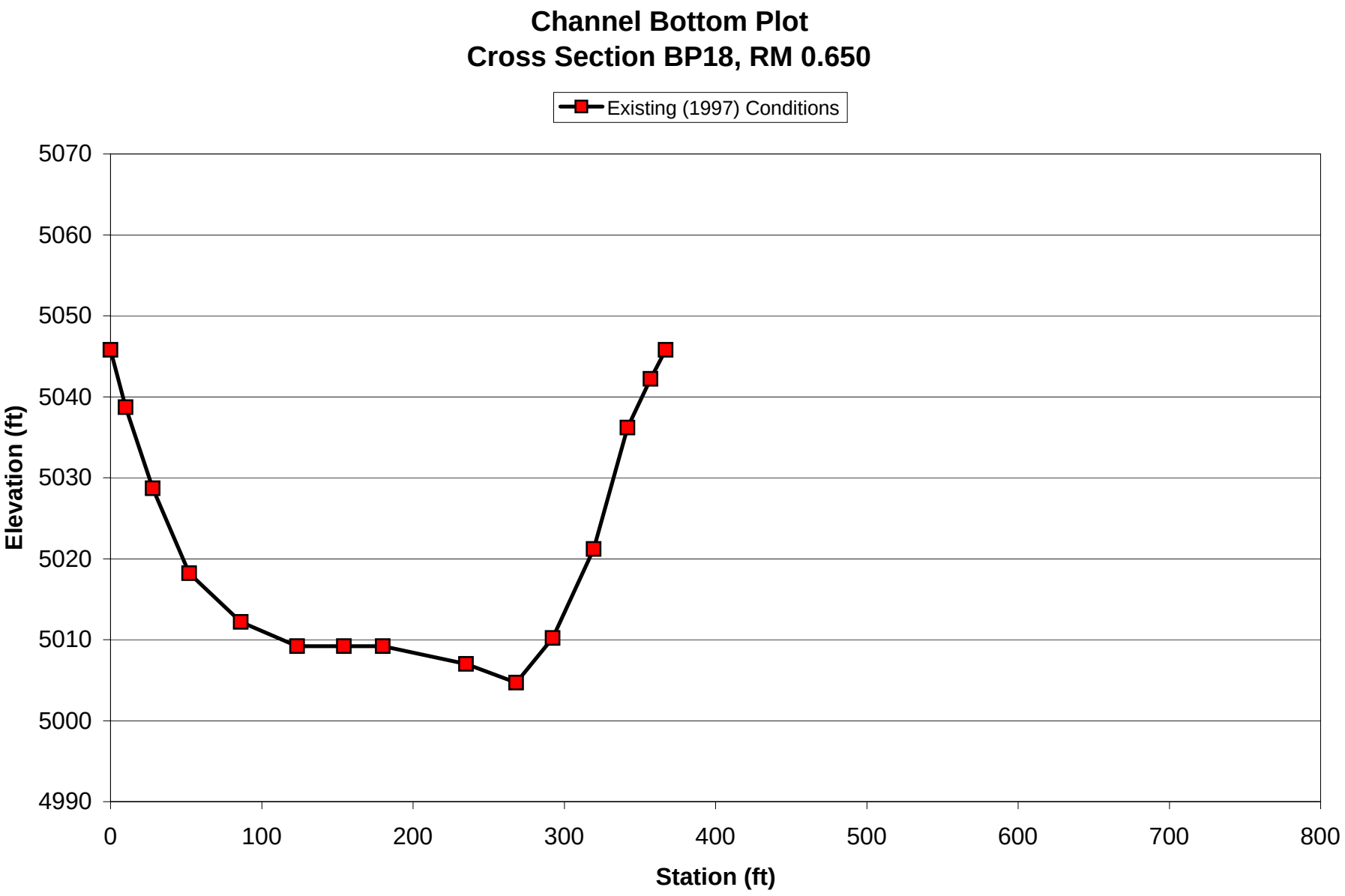

Channel Bottom Plot
Cross Section BP13, RM 0.795
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

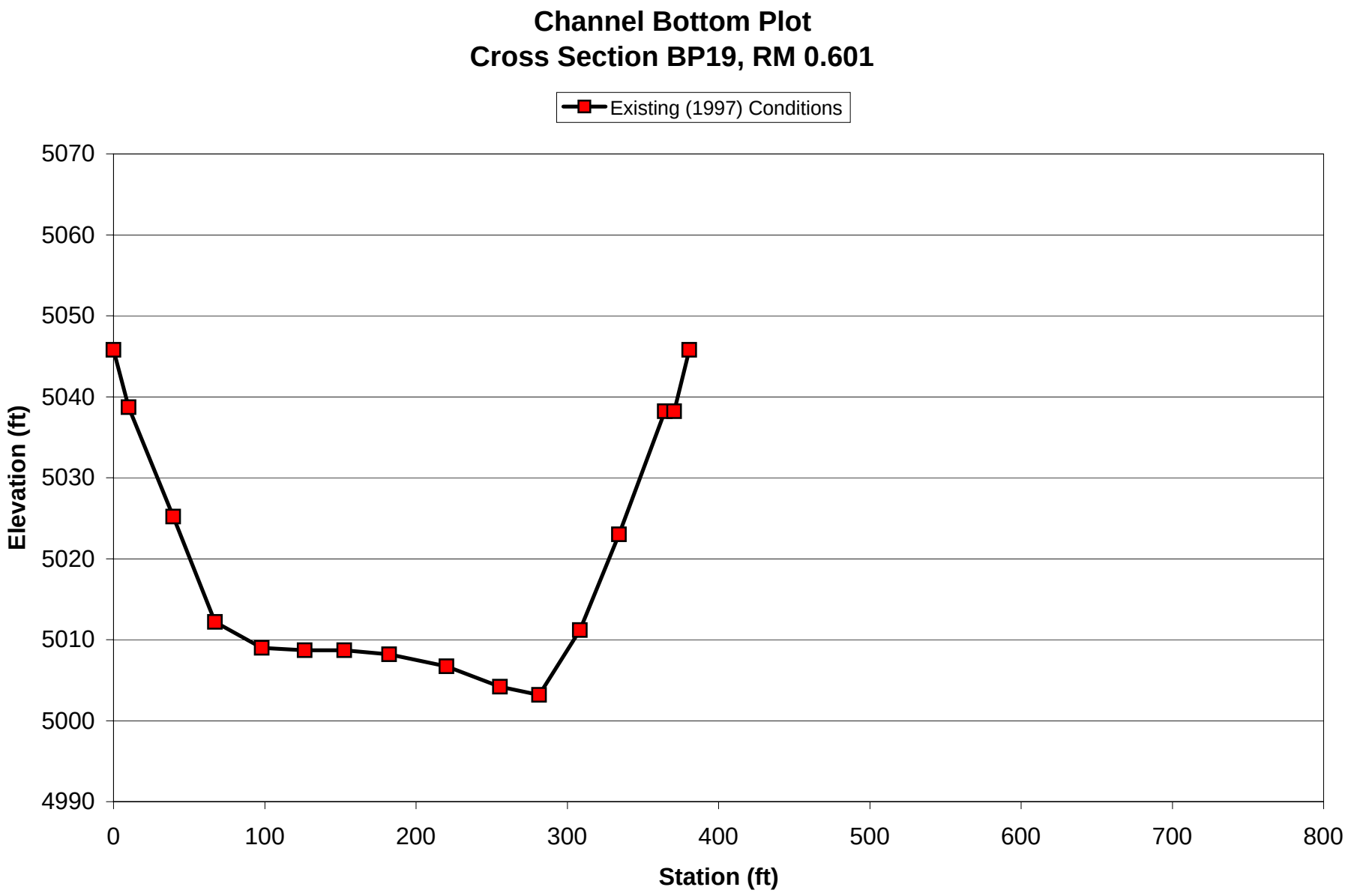

Channel Bottom Plot
Cross Section BP14, RM 0.774
Constriction
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

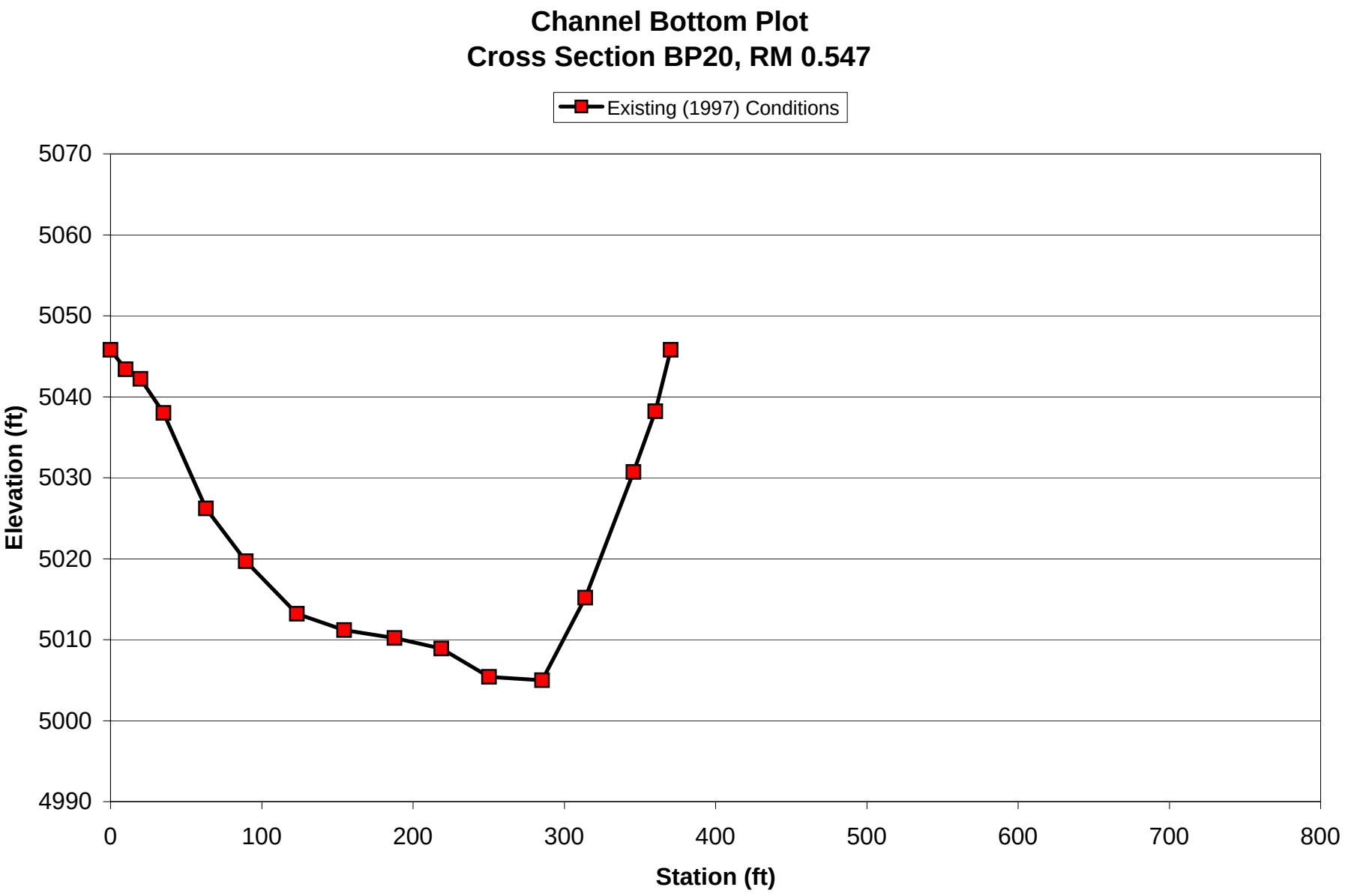

Channel Bottom Plot
Cross Section BP15, RM 0.746
Constriction
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

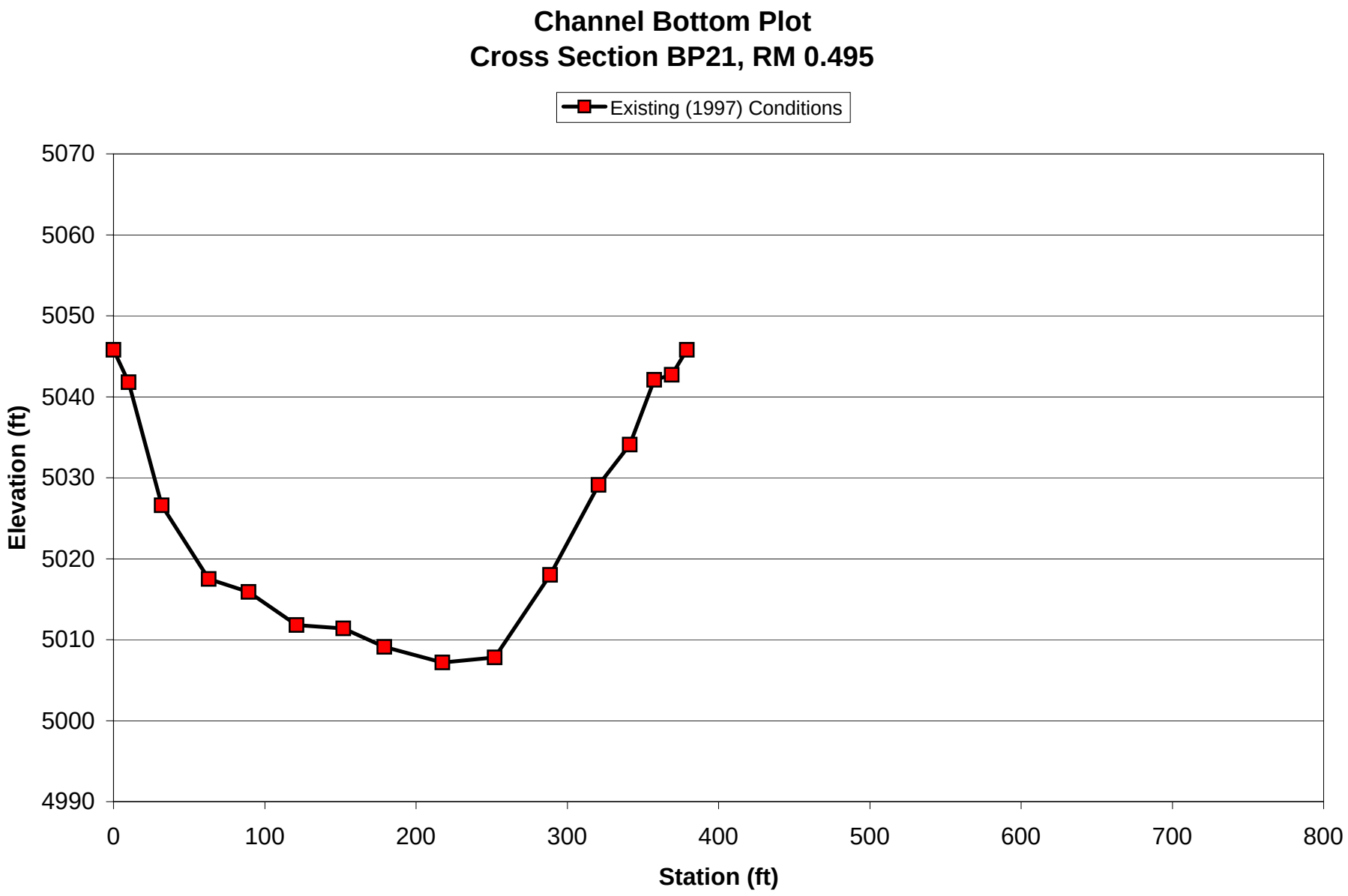

Channel Bottom Plot
Cross Section BP16, RM 0.727
Constriction
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

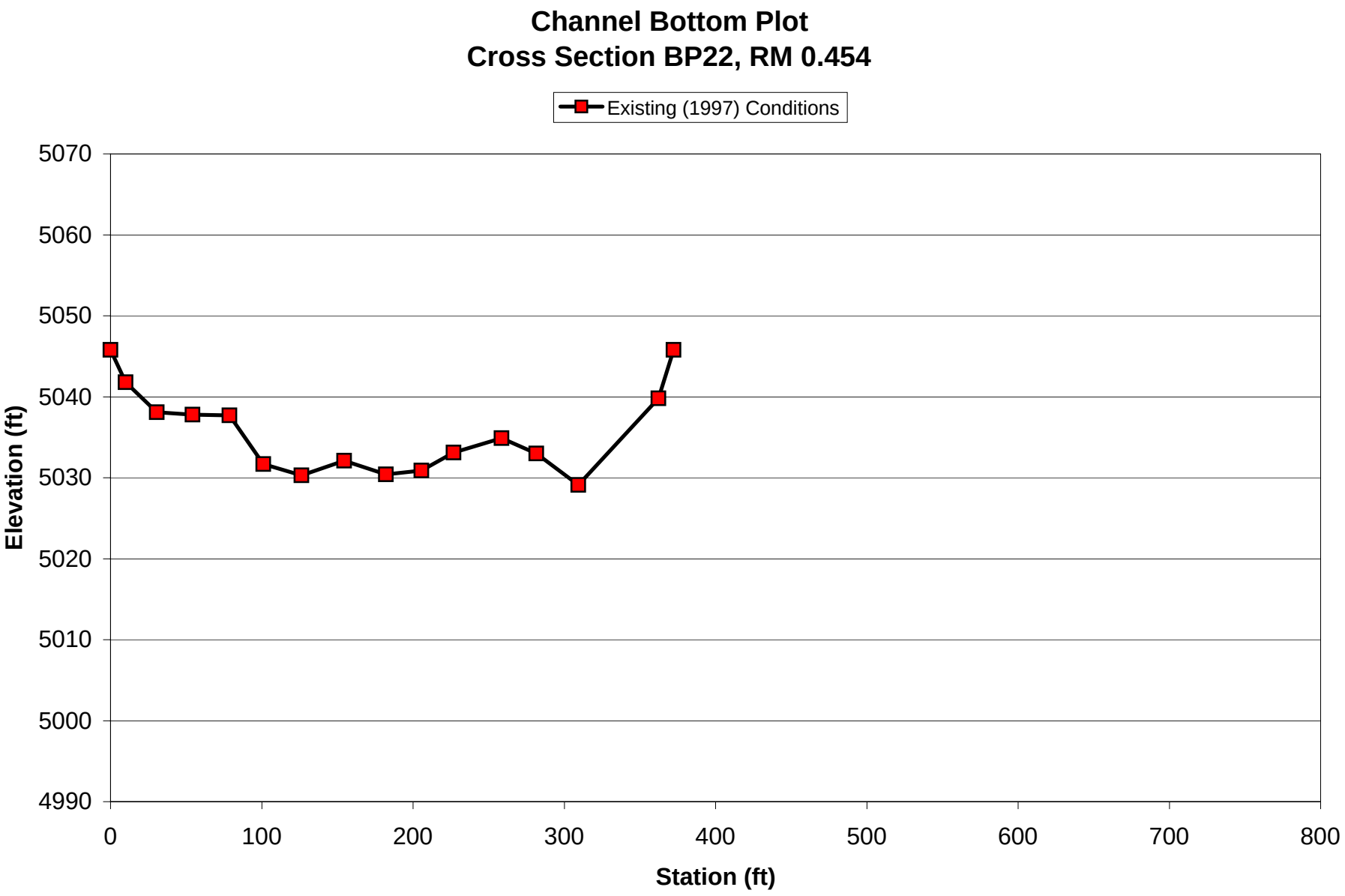

Channel Bottom Plot
Cross Section BP17, RM 0.702
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

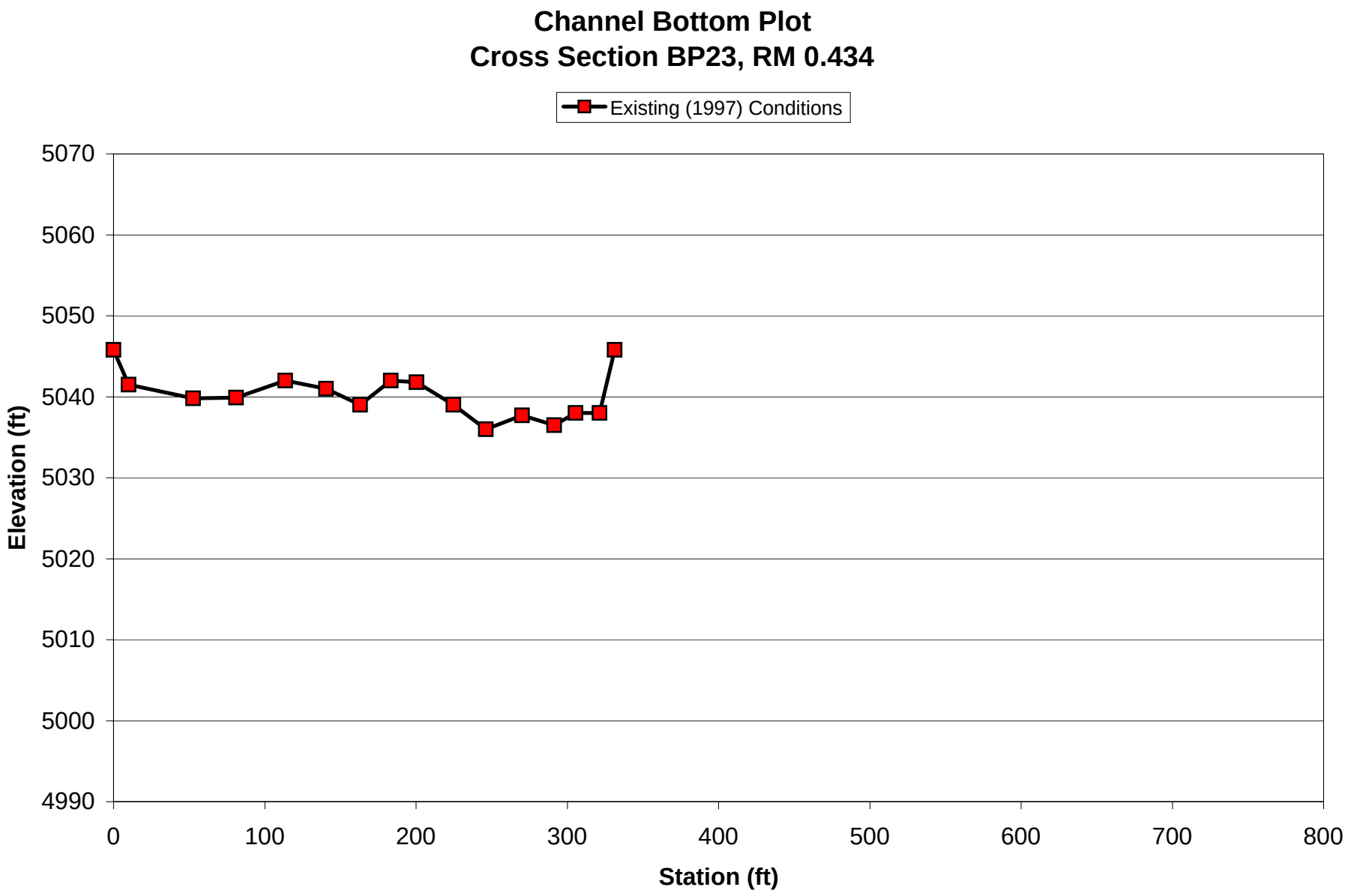

Channel Bottom Plot
Cross Section BP18, RM 0.650
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

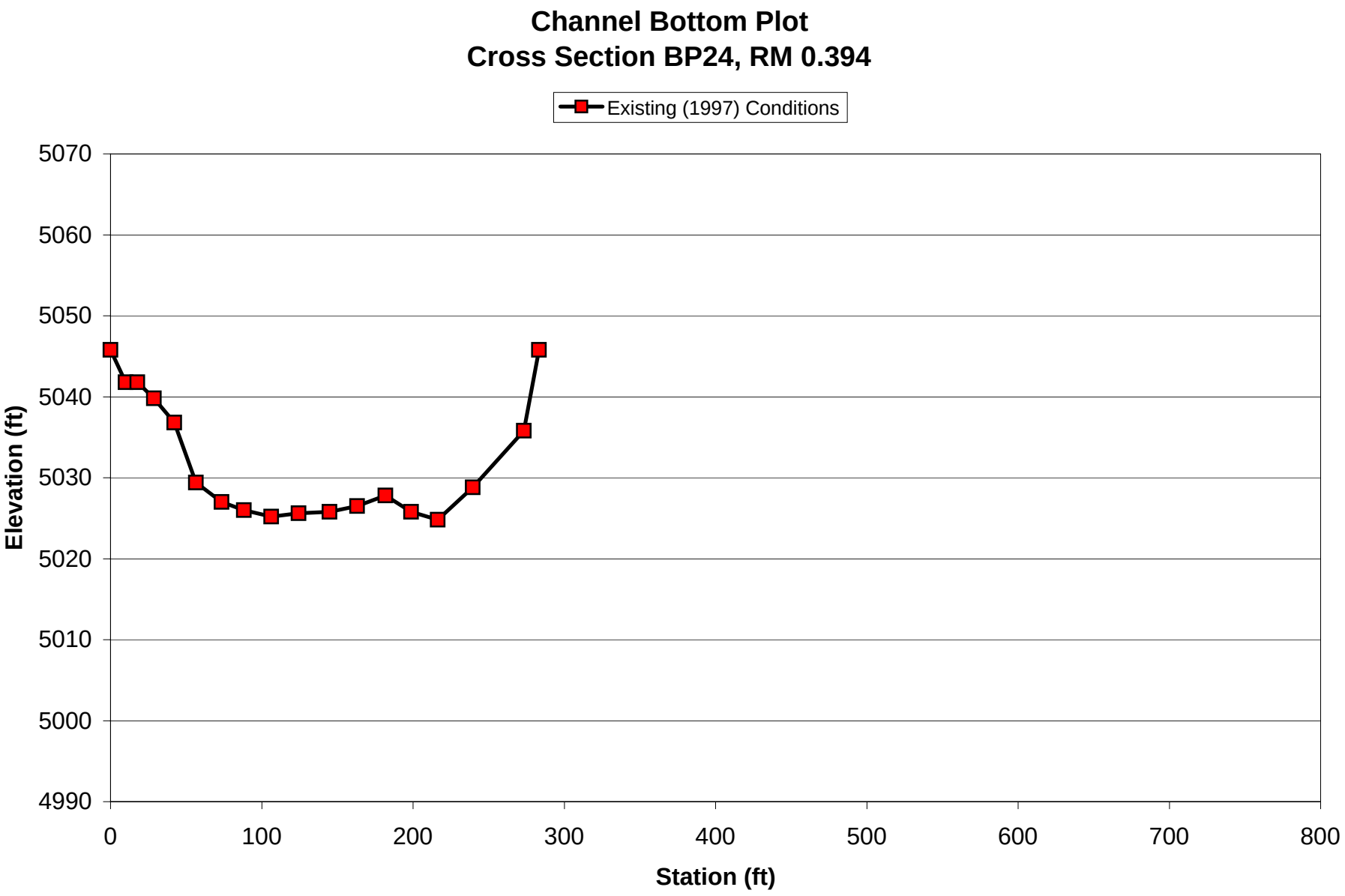

Channel Bottom Plot
Cross Section BP19, RM 0.601
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

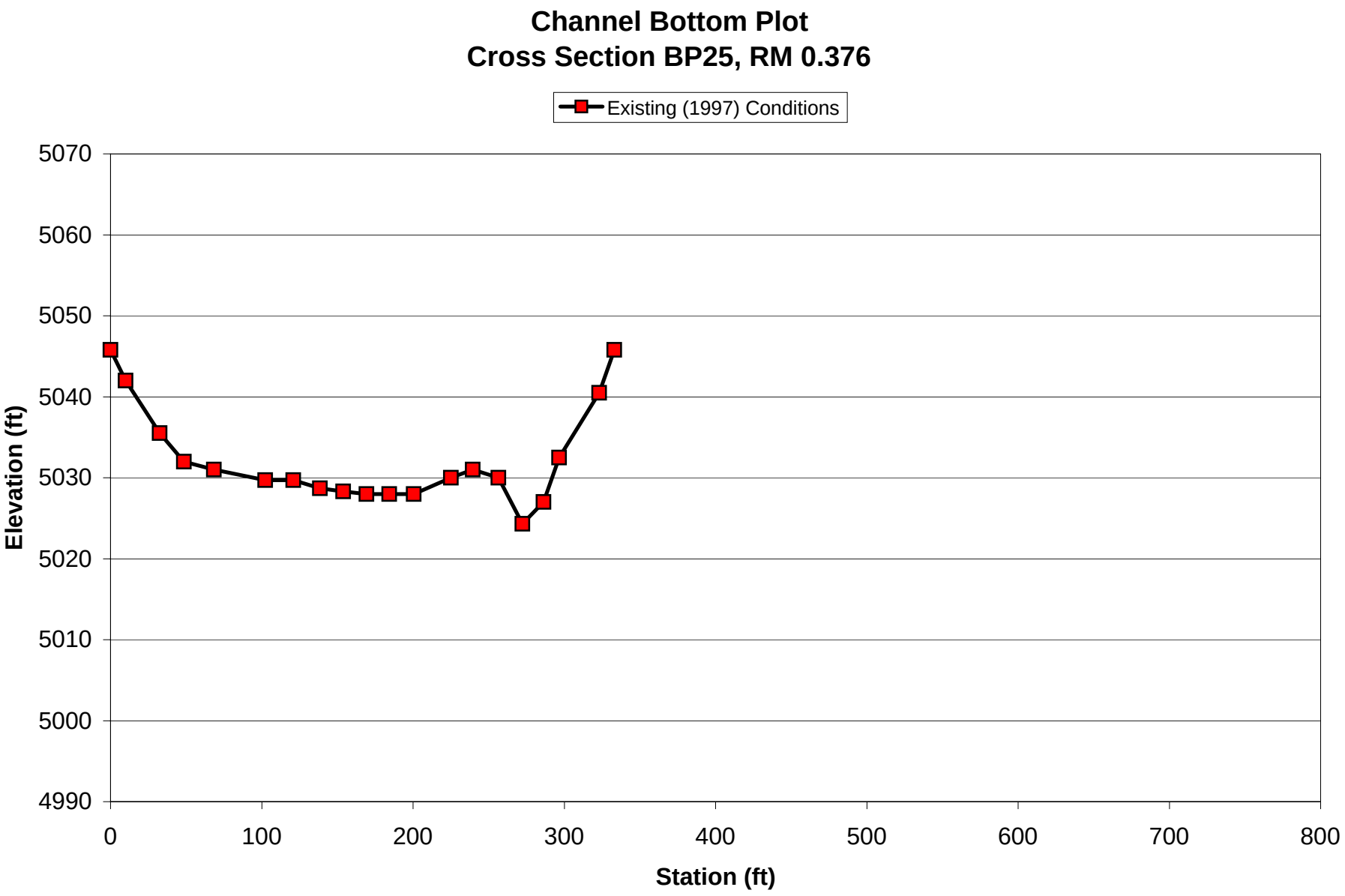

Channel Bottom Plot
Cross Section BP20, RM 0.547
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)


Channel Bottom Plot
Cross Section BP21, RM 0.495
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

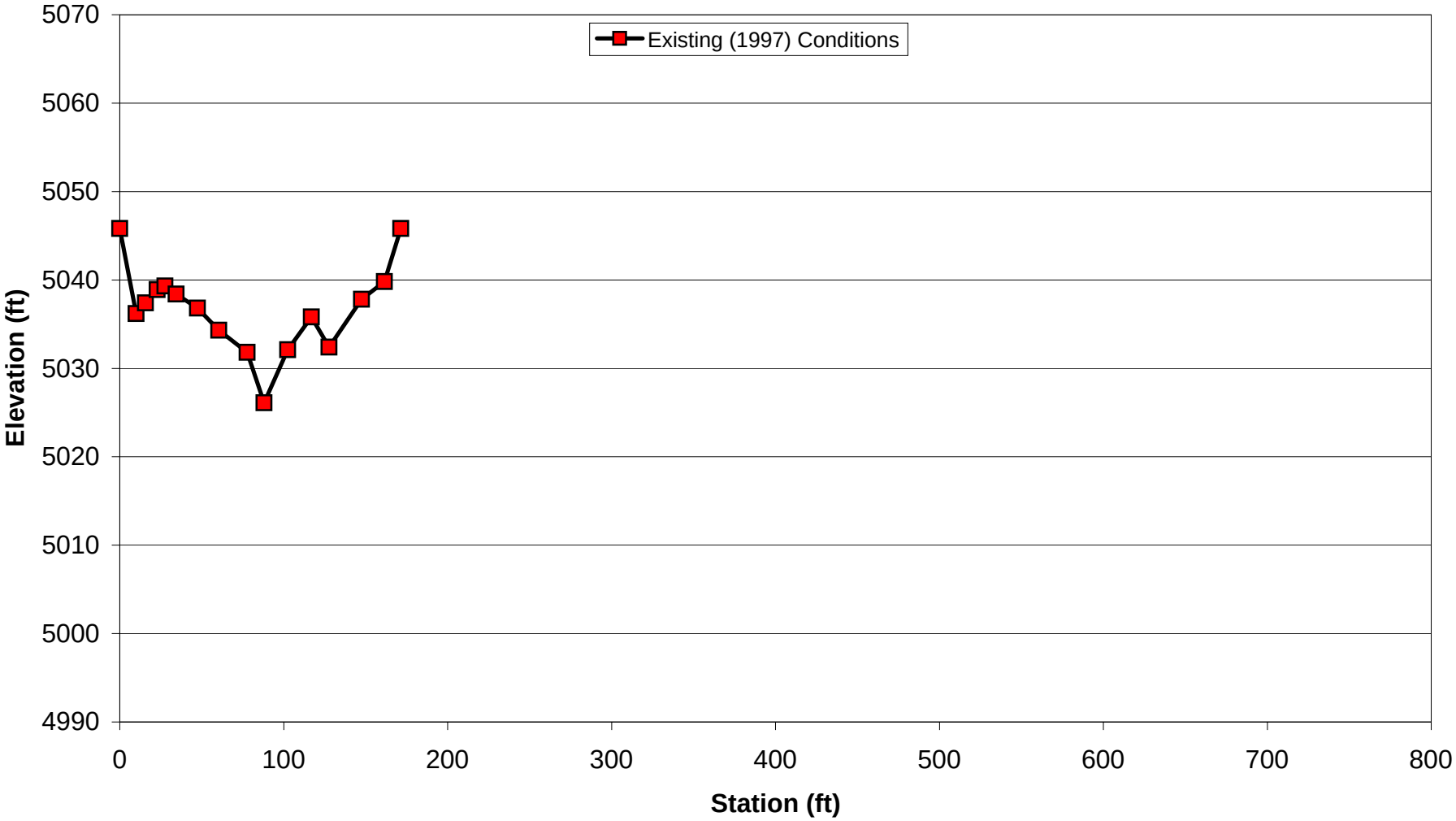

Channel Bottom Plot
Cross Section BP22, RM 0.454
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)


Channel Bottom Plot
Cross Section BP23, RM 0.434
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

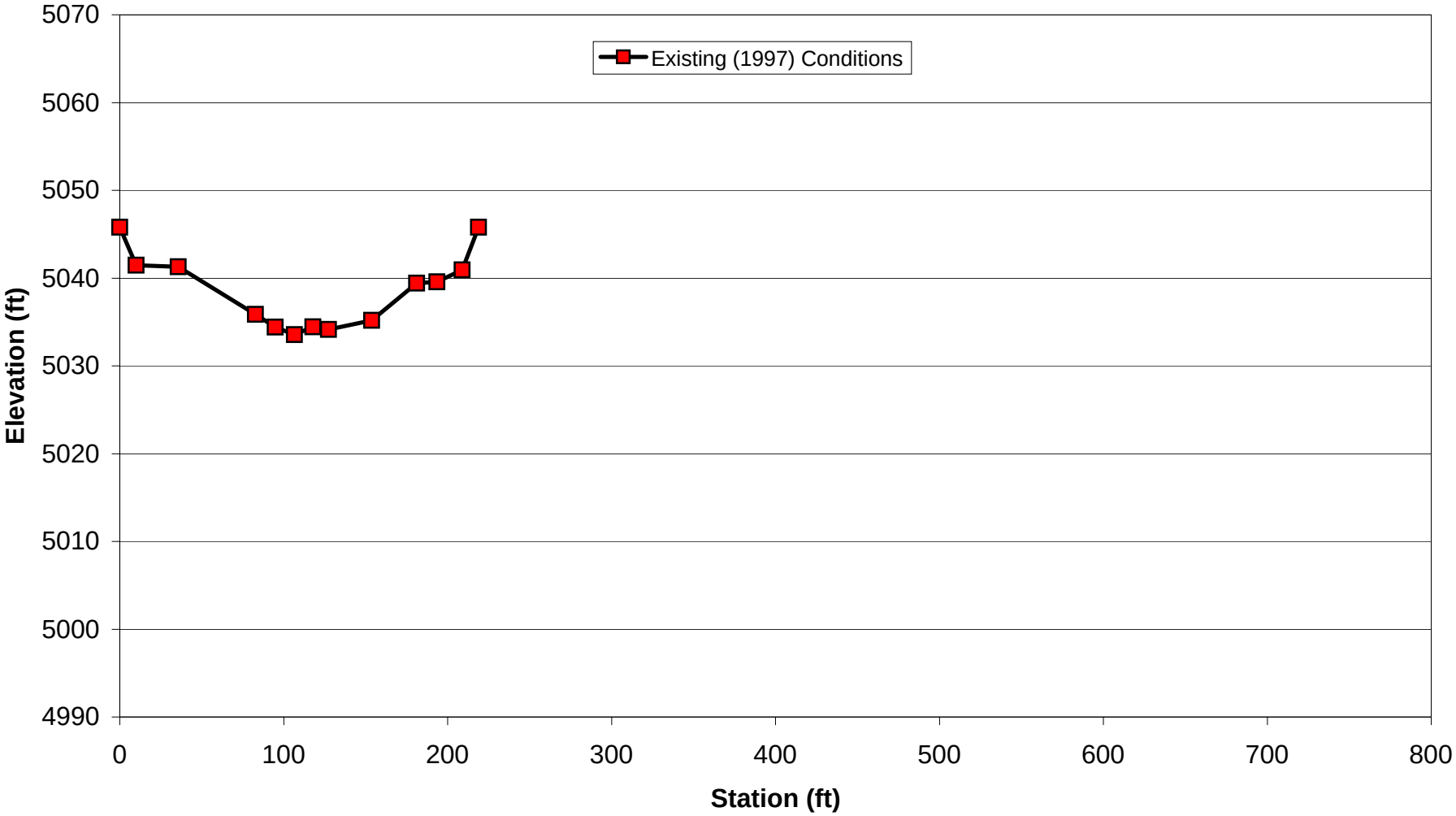

Channel Bottom Plot
Cross Section BP24, RM 0.394
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)


Channel Bottom Plot
Cross Section BP25, RM 0.376
Existing (1997) Conditions
Elevation (ft)
5070
5060
5050
5040
5030
5020
5010
5000
4990
0
100
200
300
400
500
600
700
800
Station (ft)

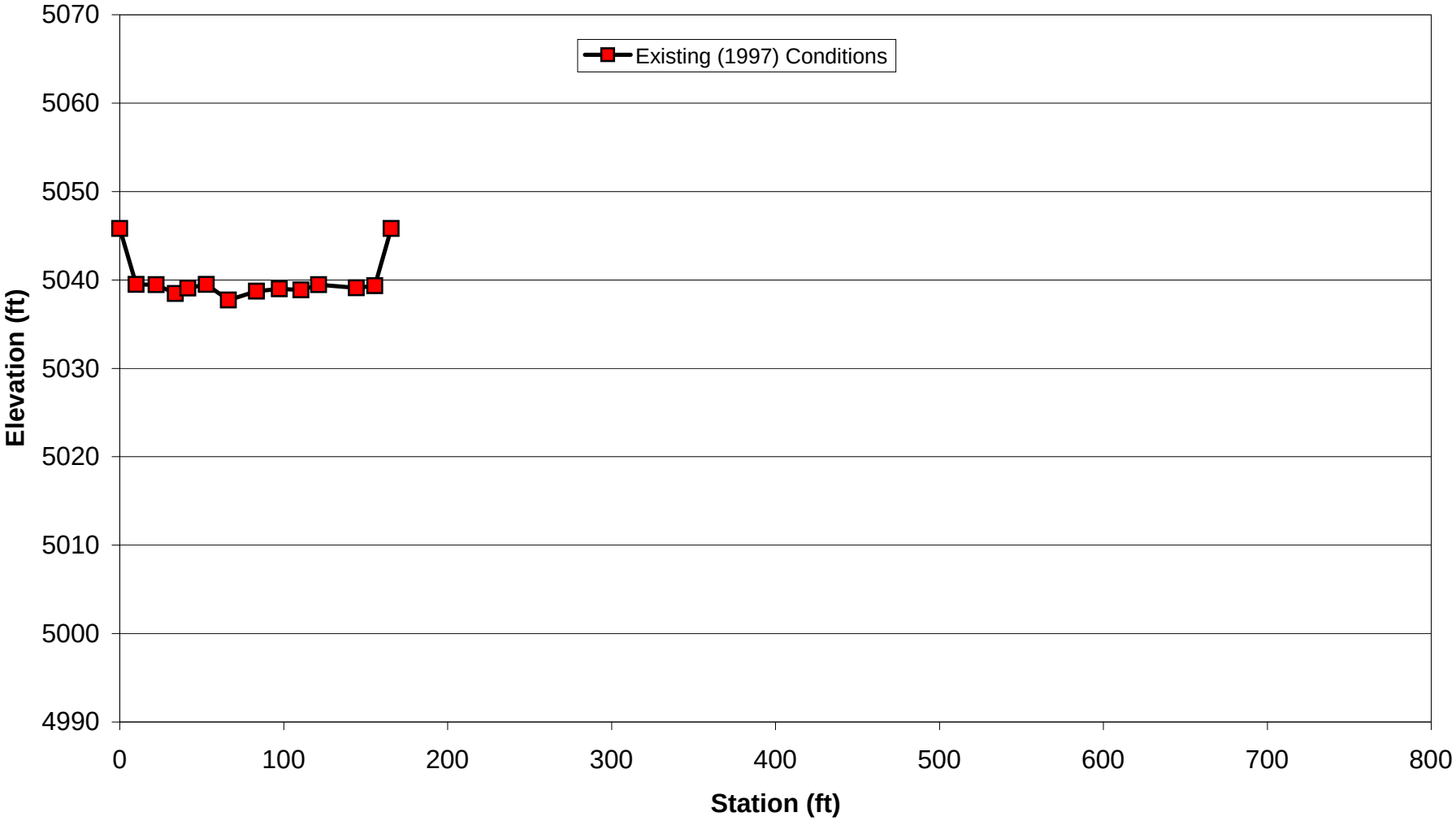
Channel Bottom Plot
Cross Section BP26, RM .348
Entrance to Diversion Channel



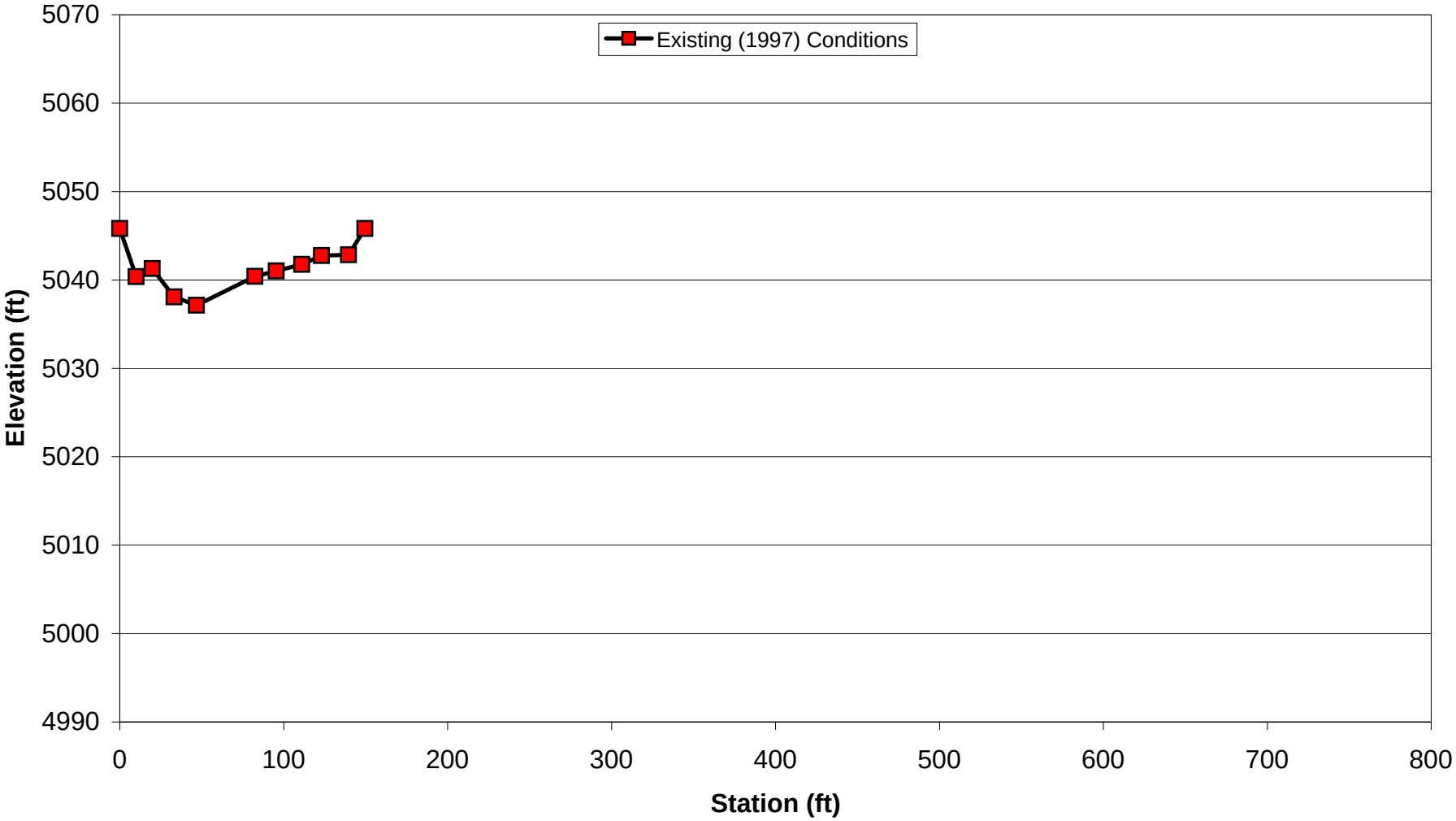
Channel Bottom Plot
Cross Section DC 3, RM 0.320
Downstream-most section in hydraulic model



Channel Bottom Plot
Cross Section DC 1
This section not in hydraulic model



Channel Bottom Plot
Cross Section DC 2
This section not in hydraulic model



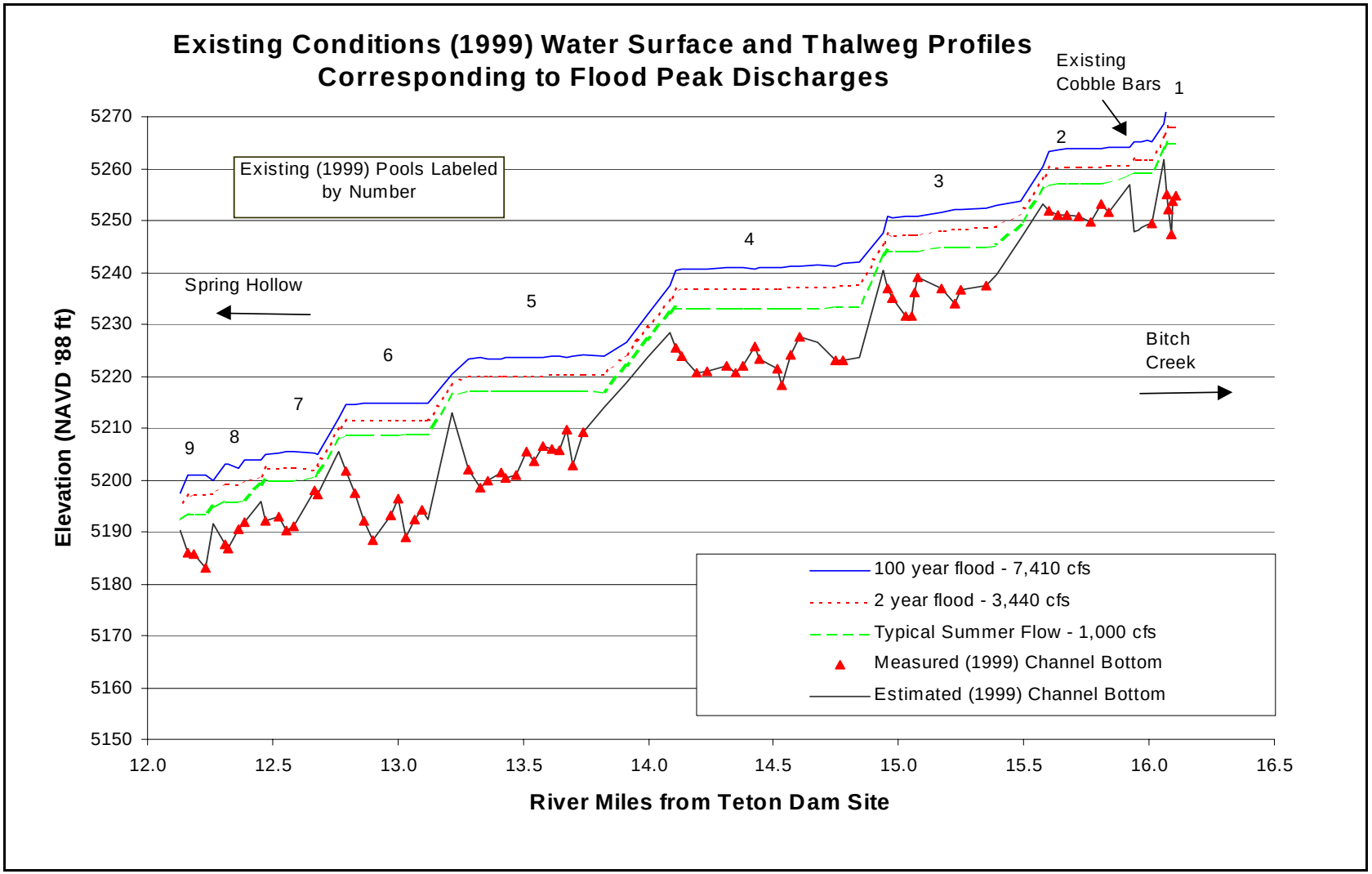


Figure H-1. Existing conditions (1999) water surface and thalweg profiles corresponding to a typical summer discharge and flood peak discharges (RM 12.1 to 16.1).

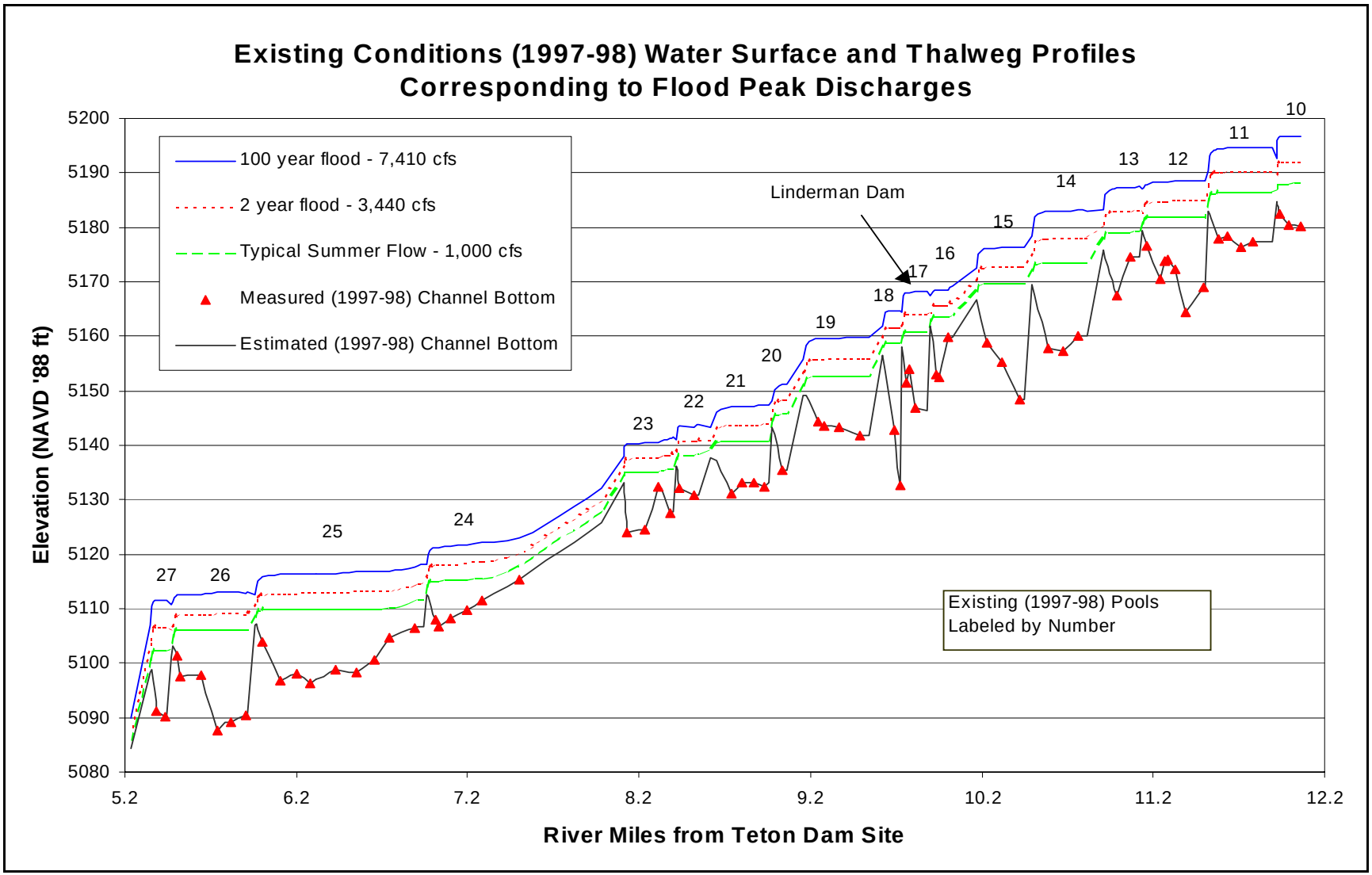


Figure H-2.—Existing conditions (1997-98) water surface and thalweg profiles corresponding to a typical summer discharge and flood peak discharges (RM 5 to 12.1).

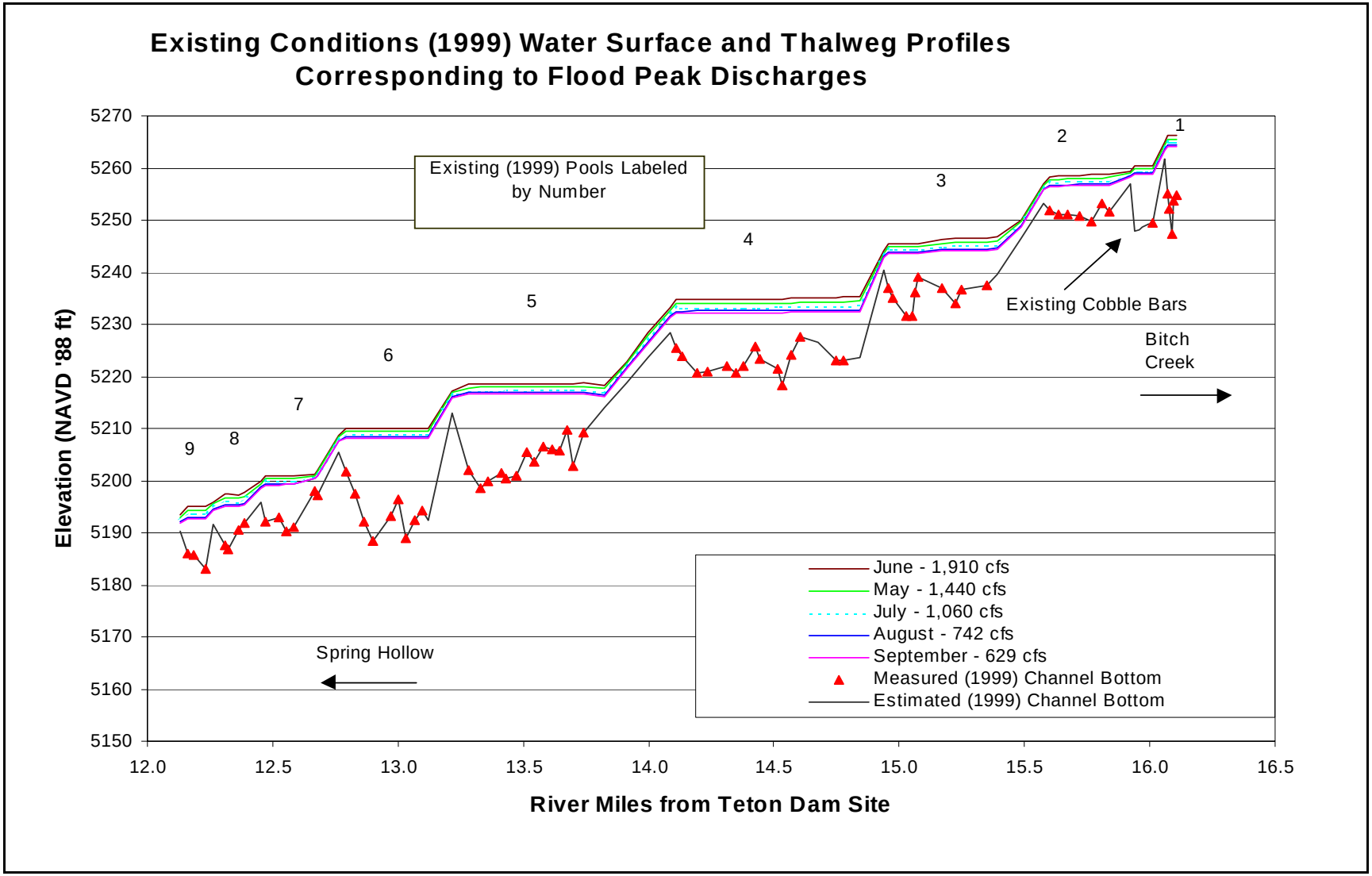


Figure H-3.—Existing conditions (1999) water surface and thalweg profiles corresponding to median summer discharges (RM 12.1 to 16.1).

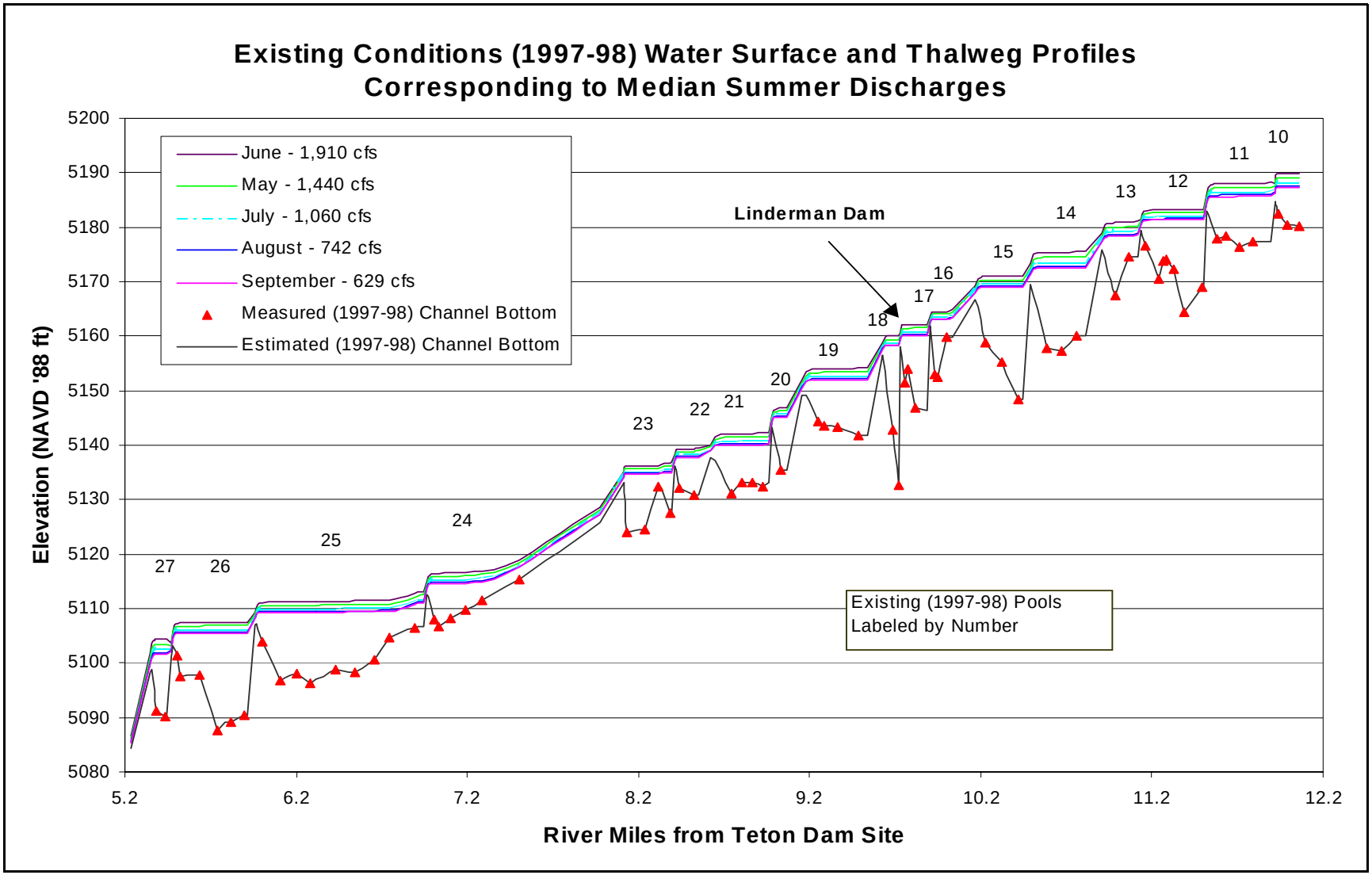


Figure H-4.—Existing conditions (1999) water surface and thalweg profiles corresponding to median summer discharges (RM 5 to 12.1).

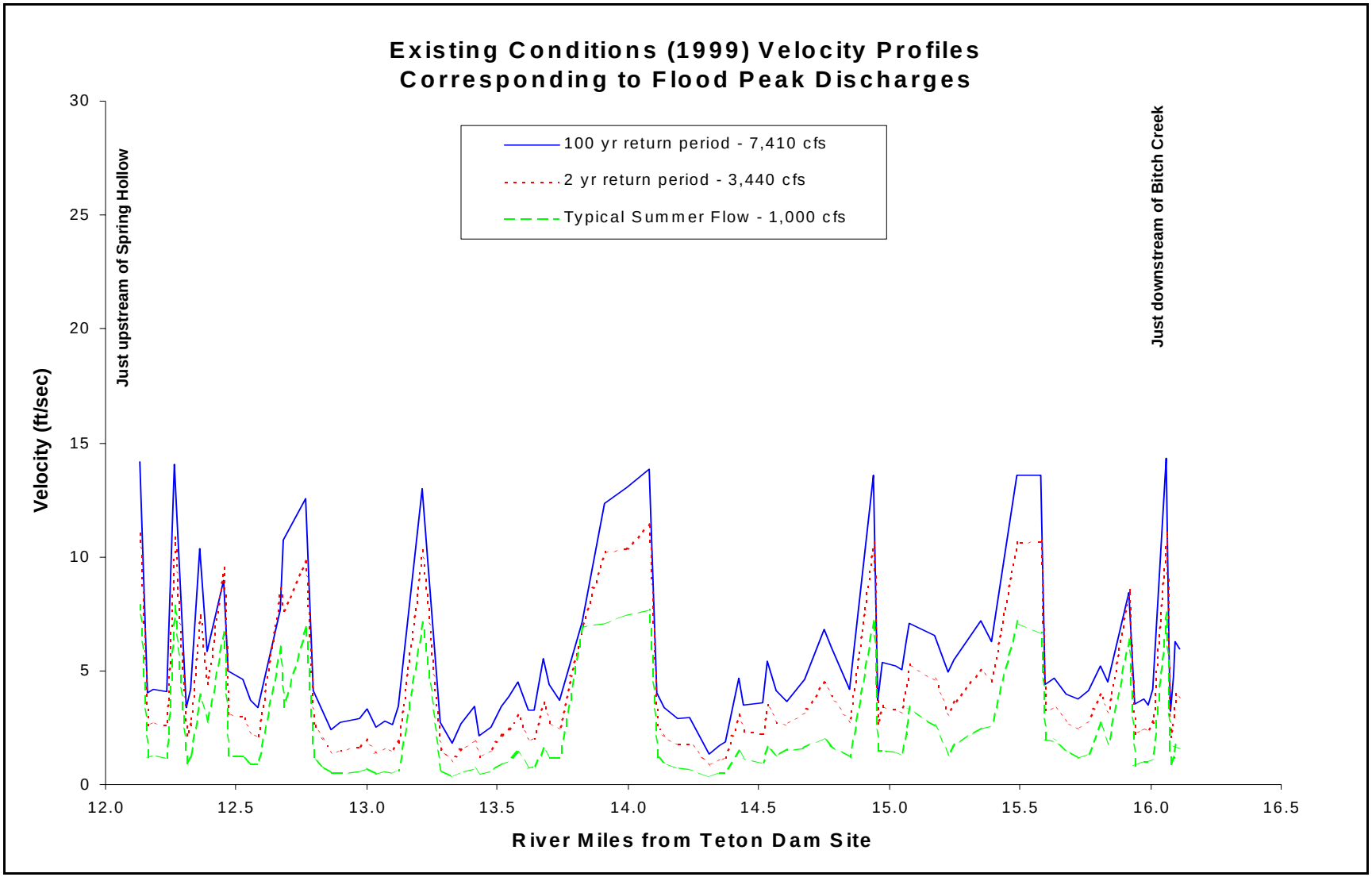


Figure H-5.—Existing conditions (1999) velocity profiles corresponding to a typical summer discharge and flood peak discharges (RM 12.1 to 16.1).

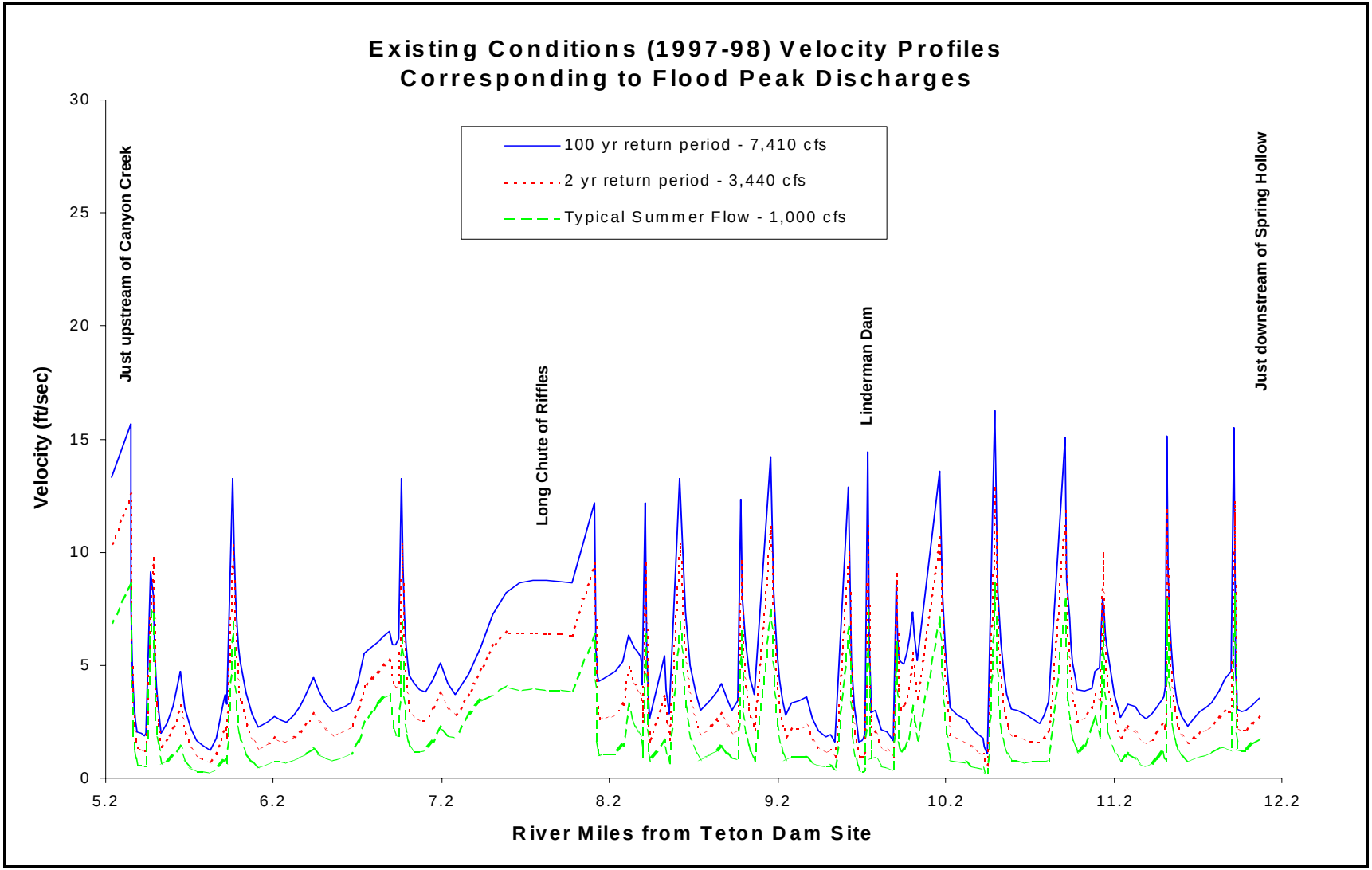


Figure H-6.—Existing conditions (1997-98) velocity profiles corresponding to a typical summer discharge and flood peak discharges (RM 5 to 12.1).

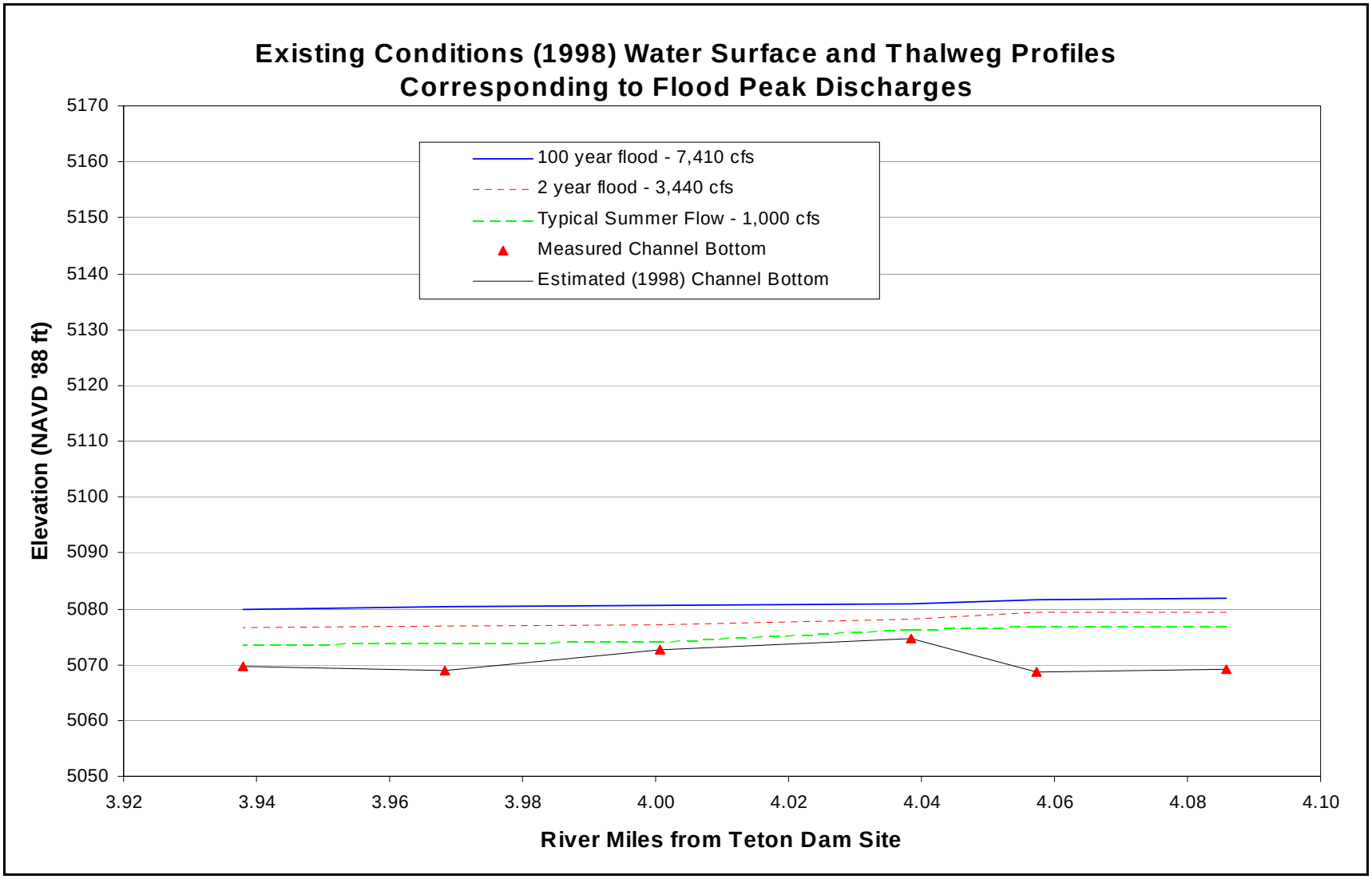


Figure H-7.—Existing conditions (1998) water surface and thalweg profiles corresponding to a typical summer discharge and flood peak discharges (RM 4).

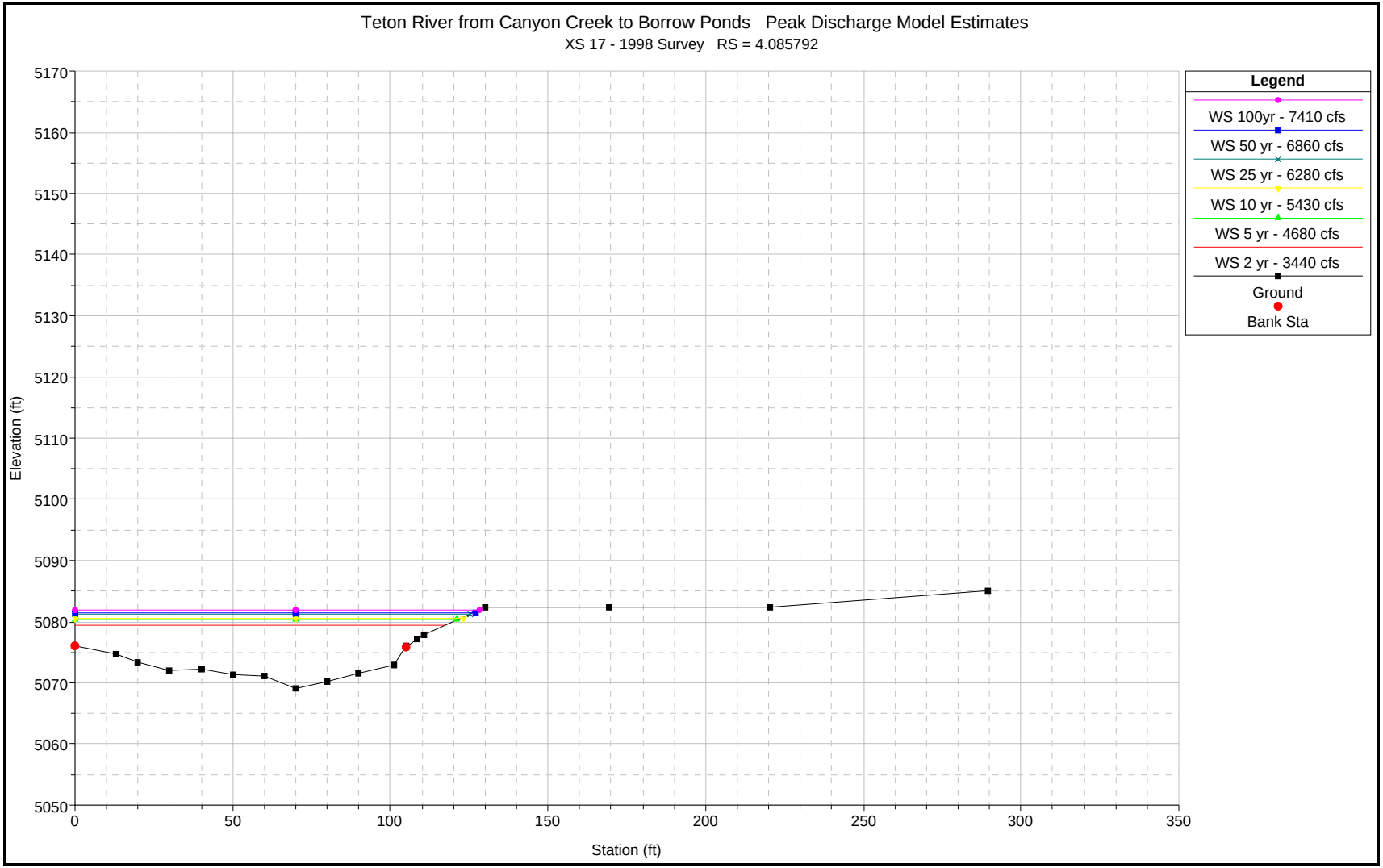


Figure H-8.— Computed water surface profiles corresponding to flood peak discharges at a section representative of Canyon Creek to Borrow Ponds reach (RM 4.086).

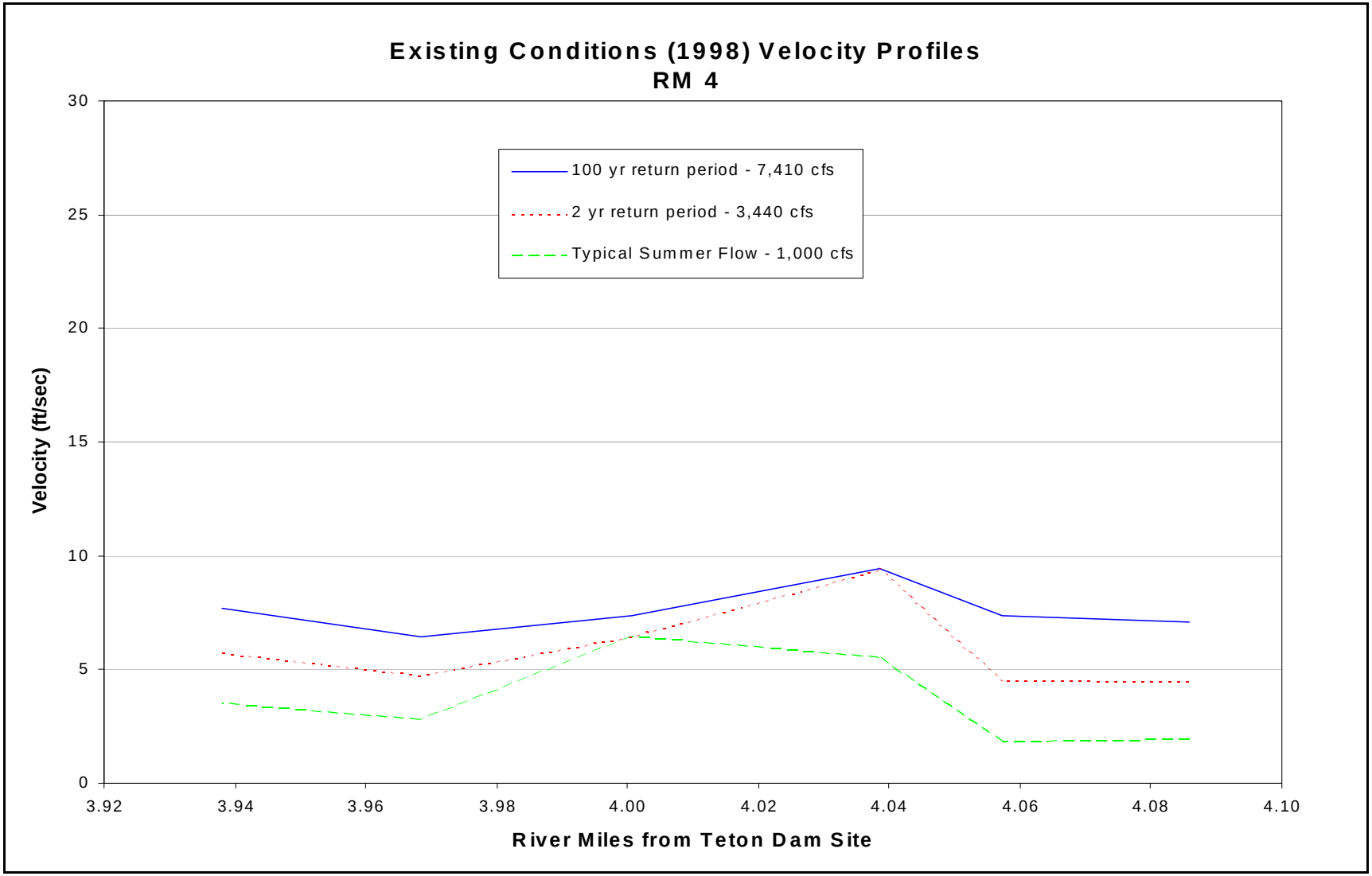


Figure H-9.—Existing conditions (1998) velocity profiles corresponding to a typical summer discharge and flood peak discharges (RM 4). In the riffle area (XS 4.04 and 4.00), the velocities for different discharges are similar because of the local cross-section geometry, where there is a large increase in river width and a small increase in water depth (see pages F-3 and F-4).

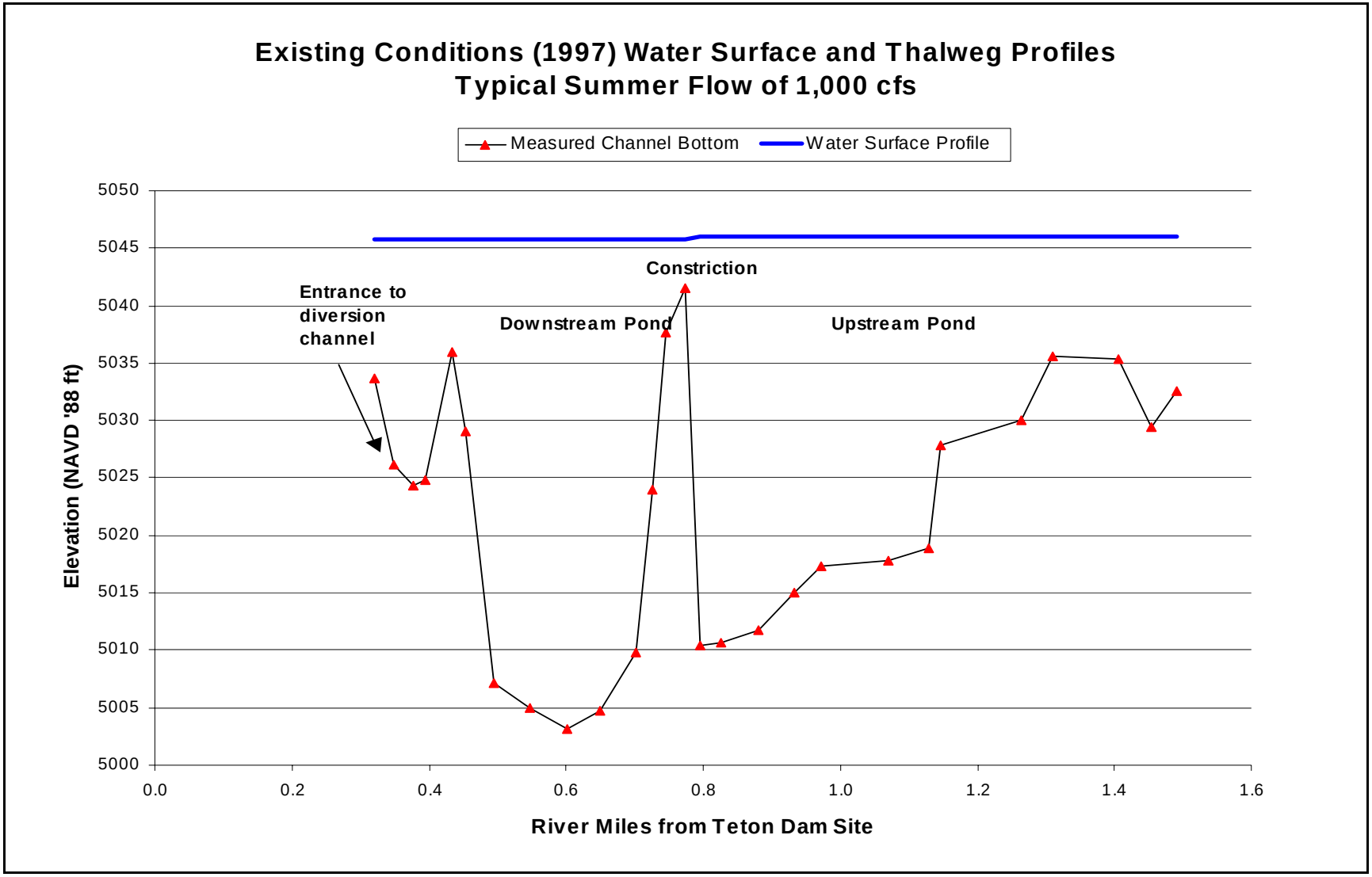


Figure H-10.—Existing conditions (1997) water surface and thalweg profile corresponding to a typical summer discharge(Borrow Ponds).

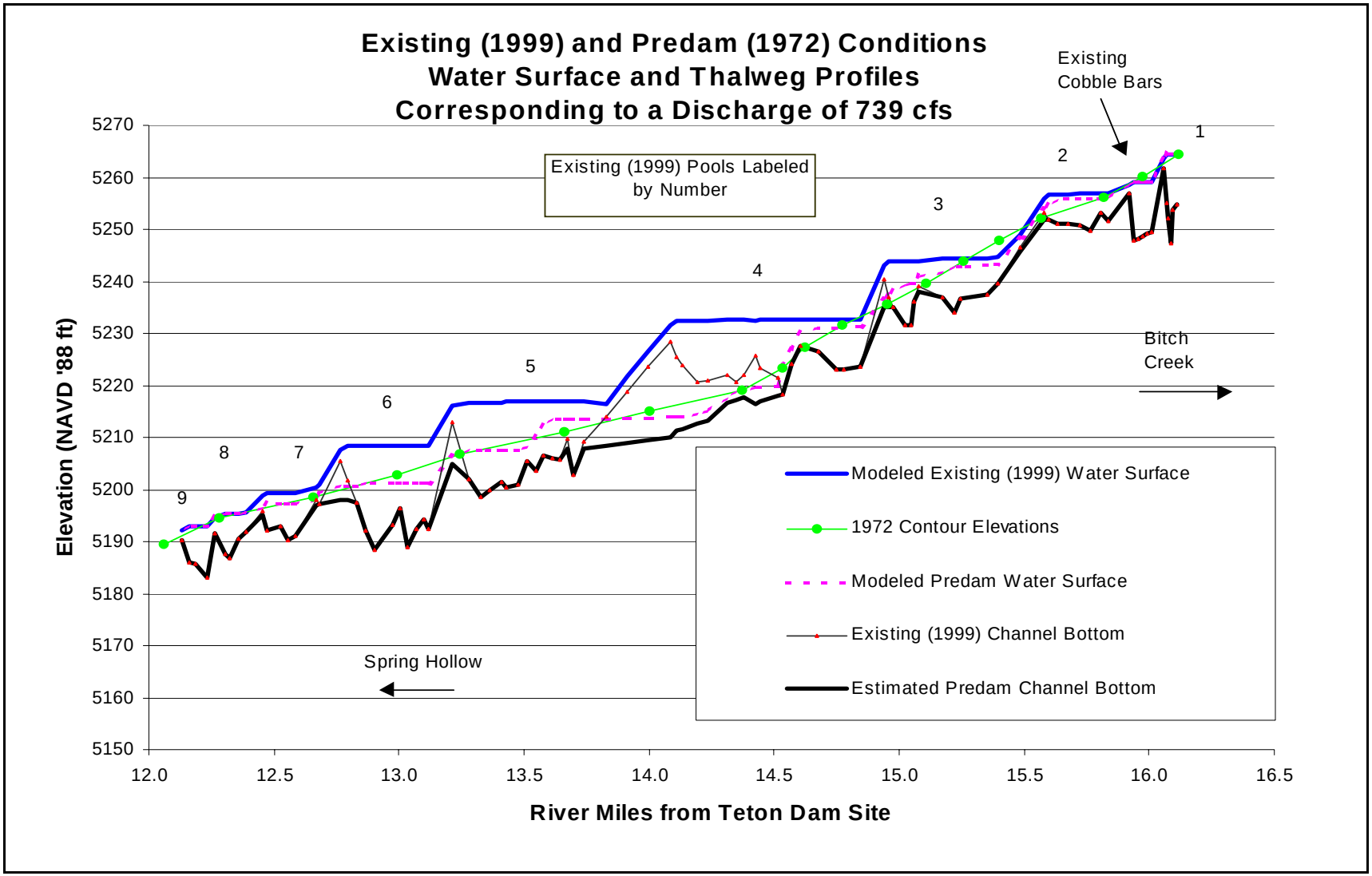


Figure H-11.—Comparison of existing conditions (1999) and predam (1972) water surface and thalweg profiles corresponding to a typical summer discharge (RM 12.1 to 16.1).

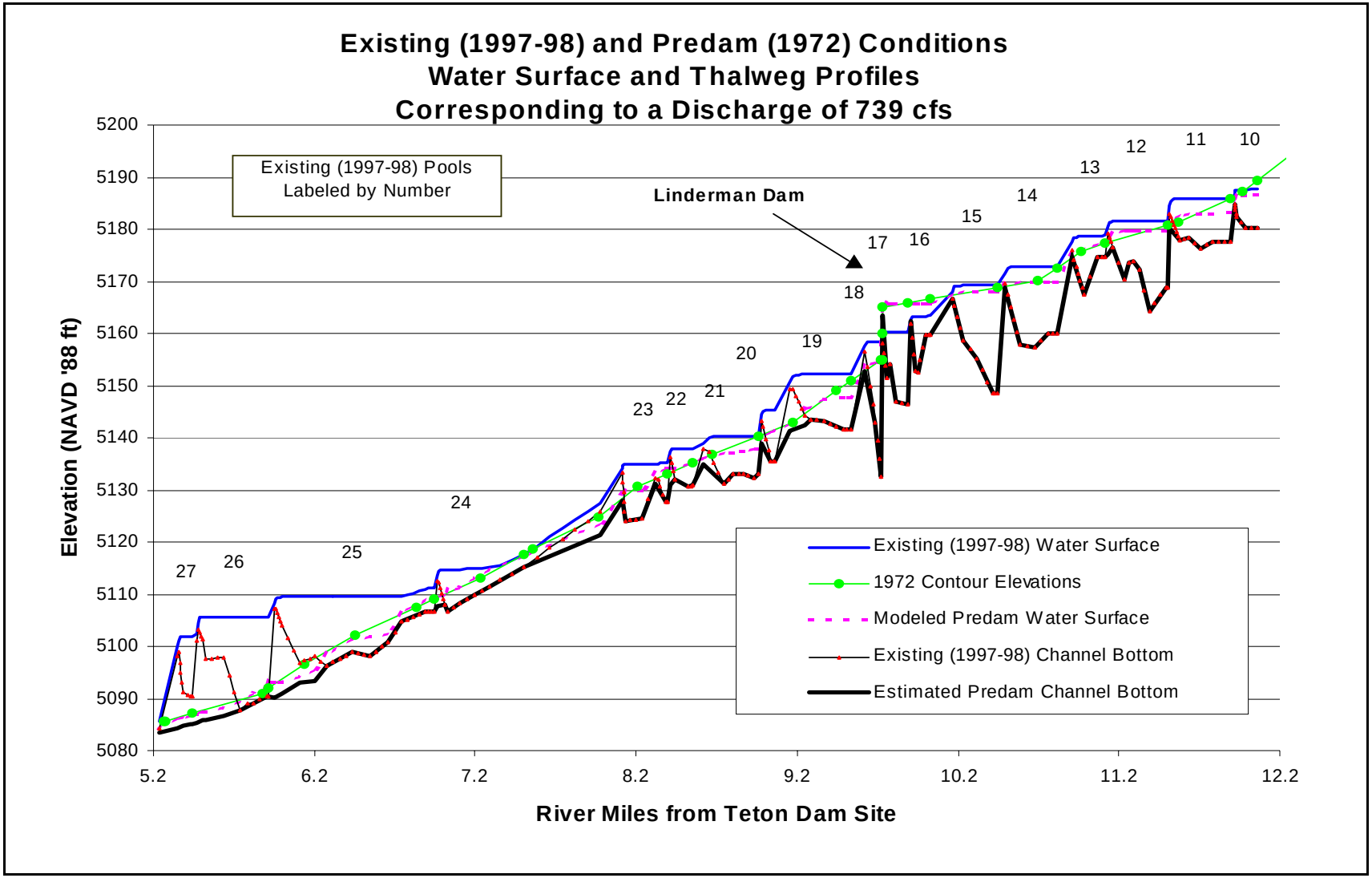


Figure H-12.—Comparison of existing conditions (1997-98) and predam (1972) water surface and thalweg profiles corresponding to a typical summer discharge (RM 5 to 12.1).

Radiocarbon Analysis and Stratigraphic Data

The fluvial stratigraphy in two natural exposures were described to provide information on the age and relative stability of the terraces along the Teton River. Bulk soil samples were collected from both sites and examined for datable material (see Puseman and Ruggiero, 1998; in this appendix). Site CC1 is located on a terrace adjacent to Canyon Creek at its confluence with the Teton River. At this site, a pre-Teton Dam terrace surface is buried by about 50-cm of well-sorted, silty sand (fig. I-1). The deposit is related to either reservoir sedimentation or deposition associated with the failure of landslides into the reservoir prior to the failure of the dam. A piece of *Alnus*-type charcoal was recovered from a buried soil just below the contact with the overlying silty sand and about a meter above the water surface of Canyon Creek. The charcoal yielded a calibrated radiocarbon age of 290-0 cal yrs B.P (see table I-1). This is consistent with the expected age of a low terrace in this position relative to river.

Figure I-1.—Weak soil developed on reservoir-related sediment at the mouth of Canyon Creek.

Site TR1 is located in a natural exposure in the right bank of the Teton River about 2000 feet downstream of the mouth of Canyon Creek. The bank is situated in the center of the canyon along the outside edge of an early Holocene or late Pleistocene terrace opposite a large landslide on the left canyon wall. As at site CC1, a pre-Teton Dam deposit at TR1 has been buried by a 10-cm-thick bed of reservoir-related sediment. Exposed in the bank is a 1-meter-thick section of interbedded clayey silt, organic-rich silt beds, sand, and gravel (fig. I-2). A piece of *Juniperus* charcoal was recovered from a buried organic bed about 50-cm below the round surface and about 50-cm above a fluvial gravel exposed at the base of the section. The charcoal yielded a calibrated radiocarbon age of 470-280 cal yrs B.P (see table I-1).

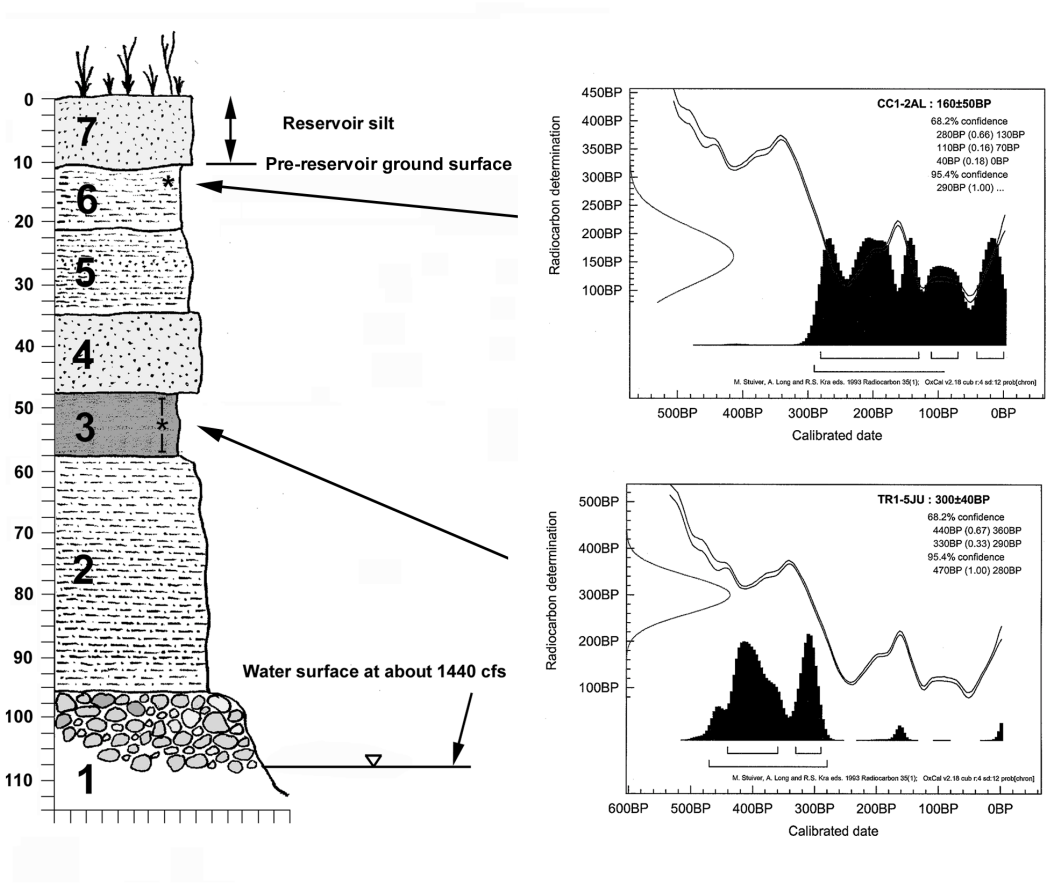


Figure I-2.—Generalized stratigraphic section and radiocarbon age determinations for fluvial deposits exposed in natural exposure downstream of Canyon Creek. Unit 1; well-rounded, well-sorted granitic and metamorphic gravel. Unit 2; light brown to gray clayey silt, thin beds up to 10 cm thick. Unit 3; dark organic-rich bed. Unit 4 medium- to fine-grained, well-sorted sand. Unit 5; clayey silt contains a thin fine-grained sand bed. Unit 6; clayey silt, sampled for radiocarbon analysis at the mouth of Canyon Creek. Unit 7; fine-grained massive silty sand (reservoir related deposit).

Due to the position of the terrace in the canyon, the post-dam deposit is believed to be the distal fine-grained facies of the large landslide on the opposite canyon wall that failed into the reservoir (i.e. turbidity flow). This interpretation is supported by observations throughout the Teton River Canyon of a general sorting of the landslide debris in a downslope direction. The coarsest material (boulders and cobbles) was deposited on the adjacent terraces or on the canyon walls just downslope of the headscarp. Finer-grained material was deposited either into the channel or completely across the channel and onto the terrace surfaces on the opposite bank.

In addition, the exposed section in the bank indicates that the terrace at this location has been relatively stable for at least the last several hundred years (470-280 cal yrs B.P.). The gravel at the bottom of the section represents an older bar deposited by the Teton River that was subsequently buried by finer-grained fluvial sediment. The character of interbedded silty sand, sand, and organic-rich beds indicates that the terrace has been slowly accreting, probably the result of shallow inundation by large floods.

Table I-1.—Radiocarbon Analysis Results for Teton River Restoration Study

Site	Field Sample Number	Laboratory Sample Number	Type of Material	Sample Weight (grams)	Radiocarbon Age (14C yrs B.P.)	Calibrated Age (cal yrs B.P.)
TR1	TR1-5JU	Beta-121553	*Juniperus* charcoal	0.122	300±40	470-280
CC1	CC1-2AL	Beta-121554	*Alnus* charcoal	0.007	160±50	290-0

EXAMINATION OF BULK SOIL FROM THE TETON RIVER, IDAHO

By

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Paleo Research Labs Technical Report 98-72

Prepared For

U.S. Bureau of Reclamation
Denver Federal Center
Denver, Colorado

August 1998

Introduction

Bulk soil samples were recovered from natural exposures in stream terraces adjacent to the Teton River near the Idaho-Wyoming state line in Idaho. Botanic components and detrital charcoal were identified, and potentially radiocarbon datable material was separated.

Methods

The samples were floated using a modification of the procedures outlined by Matthews (1979). Each sample was added to approximately 3 gallons of water. The sample was stirred until a strong vortex formed, which was allowed to slow before pouring the light fraction through a 150 micron mesh sieve. Additional water was added and the process repeated until all visible macrofloral material was removed from the sample (a minimum of 5 times). The material which remained in the bottom (heavy fraction) was poured through a 0.5 mm mesh screen. The floated portions were allowed to dry.

The light fractions were weighed, then passed through a series of graduated screens (US Standard Sieves with 4 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm openings to separate charcoal debris and to initially sort the remains. The contents of each screen were then examined. Charcoal pieces larger than 1 mm in diameter were broken to expose a fresh cross-section and examined under a binocular microscope at magnifications up to 140x. The remaining light fraction in the 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm sieves was scanned under a binocular stereo microscope at a magnification of 10x, with some identifications requiring magnifications of up to 70x. The material which passed through the 0.25 mm screen was not examined. The coarse or heavy fractions also were screened and examined for the presence of botanic remains.

Macrofloral remains, including charcoal, were identified using manuals (Core et al. 1976; Martin and Barkley 1973; Panshin and Zeeuw 1980; Petrides and Petrides 1992) and by comparison with modern and archaeological references. The term "seed" is used to represent seeds, achenes, caryopses, and other disseminules. Remains from both the light and heavy fractions were recorded as charred and/or uncharred, whole and/or fragments. Because charcoal and possibly other botanic remains were to be sent for radiocarbon dating, clean laboratory conditions were used during the flotation and identification to avoid contamination. All instruments were washed between samples, and samples were protected from contact with modern charcoal.

Discussion

The sampled stream terraces were located adjacent to the Teton River where it flows through a narrow canyon on the eastern edge of the Snake River plain at an elevation between 5200 and 5400 feet. Vegetation on the south-facing slopes in the canyon is dominated by juniper (Juniperus) and sagebrush (Artemisia), while the north-facing slopes contain pine (Pinus), aspen (Populus), and ir (Abies). The canyon bottom supports a thin riparian corridor with cottonwood (Populus), hawthorn (Crataegus), chokecherry (Prunus virginiana), and willow (Salix). Four bulk samples were recovered from the study.

Sample TR1-5 was collected from a depth of 48-58 cm (Table 1). This sample contained two charred Juniperus seed fragments, five small, charred, unidentifiable seed fragments, and a piece of charred PET fruity tissue that may represent a fleshy fruit or berry that burned (Tables 2 and 3). Uncharred seeds and rootlets represent modern plants. A few sclerotia also were present. Sclerotia are commonly called "carbon balls". They are small, black, solid or hollow balls that range from 0.5 to 4mm in size. Sclerotia are associated with mycorrhizae fungi, such as Cenococcum graniforme, that have a mutualistic relationship with tree roots. Sclerotia are the resting structures of the fungus, identified by Dr. Kristiina Vogt, Professor of Ecology in the School of Forestry and Environmental Studies at Yale University. Many trees are noted to depend heavily on mycorrhizae and may not be successful without them. "The mycelial strands of these fungi grow into the roots and take some of the sugary compounds produced by the tree during photosynthesis. However, mycorrhizal fungi benefit the tree because they take in minerals from the soil, which are then used by the tree" (Kricher and Morrison 1988:285). Sclerotia appear to be ubiquitous and are found with coniferous and deciduous trees including Abies (fir), Juniperus communis (common juniper), Larix (larch), Picea (spruce), Pinus (pine), Pseudotsuga (Douglas fir), Acer pseudoplatanus (sycamore maple), Alnus (alder), Betula (birch), Carpinus caroliniana (American hornbeam), Carya (hickory), Castanea dentata (American chestnut), Corylus (hazelnut), Crataegus monogyna (hawthorn), Fagus (beech), Populus (poplar, cottonwood, aspen), Quercus (oak), Rhamnus fragula (alder bush), Salix (willow), Sorbus (chokecherry), and Tilia (linden) (McWeeney 1989:229-130; Trappe 1962).

Several datable charcoal and wood types were present in sample TR1-5. The charcoal record was dominated by Juniperus, with a smaller amount of Salicaceae charcoal present. Pieces of uncharred Juniperus wood also were present, as well as possible Prunus and conifer wood. Non-floral remains included small pieces of uncharred bone, a fish scale, insect fragments, snails, and rock/gravel.

Sample TR4-2 represents the B horizon at a depth of 25-50 cm, and sample TR4-3 represents the B horizon at a depth of 50-78 cm. Neither of these samples contained any datable material. Uncharred rootlets from modern plants, insect fragments, and rock/gravel were the only remains recovered in each of these two samples.

Sample CC1-2 was taken from a buried soil at a depth of 50 cm below the surface. A charred Poaceae seed fragment represents grass that burned. Uncharred seeds and rootlets again represent modern plants. Sufficient quantity of Alnus-type charcoal was recovered for AMS dating. Pieces of Betula-type, Salicaceae, and small, unidentifiable charcoal also were present. Since alder and birch are not noted in the immediate study area, these charcoal pieces may have been carried down from riparian habitats found upriver of the study area. Pieces of uncharred Salicaceae wood also were present. Sclerotia, insect fragments, snails, and rock/gravel complete the record.

Summary and Conclusions

Flotation of four samples from terraces adjacent to the Teton River near the Idaho-Wyoming state line resulted in recovery of charcoal and wood that may be sent for radiocarbon dating. Charred and uncharred plant remains represent plants found in the immediate study area as well as habitats found upriver of the Teton River, possibly from the Teton Range to the east.

Table 1.— Provenance Data for Samples From the Teton River, Idaho

Sample No.	Depth below surface	Description
TR1-5	48-58 cm	Bulk sediment, Bed 5
TR4-2	25-50 cm	Bulk sediment from the upper half of the B horizon
TR4-3	50-78 cm	Bulk sediment from the lower half of the B horizon
CC1-2	50 cm	Bulk sediment from buried soil below dam debris at the mouth of the canyon creek

Table 2.—Macrofloral Remains From the Teton River, Idaho

Sample			Charred		Uncharred		Weights/
No.	Identification	Part	W	F	W	F	Comments
TR1-5	Liters Floated						1.8 L
48-58	Light Fraction Weight						5.10 g
cm	FLORAL REMAINS:						
	Juniperus	Seed		2			0.004 g
	Unidentified	Seed		5			0.004 g
	PET Fruity	Tissue		1			<0.001 g
	Asteraceae	Seed			2		
	Carex	Seed			11		
	Chenopodium	Seed			5		
	Scrophulariaceae	Seed			1		
	Rootlets					X	Numerous
	Sclerotia				X		Few
	CHARCOAL/WOOD:						
	Juniperus	Charcoal		36			0.122 g
	Salicaceae	Charcoal		5			0.030 g
	Unidentified	Charcoal		X			0.028 g
	Conifer	Wood				1	<0.001 g
	Juniperus	Wood				8	0.050 g
	cf. Prunus	Wood				4	0.201 g
	NON-FLORAL REMAINS:						
	Bone					21	0.008 g
	Fish scale				1		
	Insect	Chitin				39	
	Rock/Gravel					X	Moderate
	Snail				X	X	0.184 g
TR4-2	Liters Floated						1.0 L
25-50	Light Fraction Weight						2.67 g
cm	FLORAL REMAINS:						
	Rootlets					X	Numerous
	NON-FLORAL REMAINS:						
	Insect	Chitin				10	
	Rock/Gravel					X	Moderate

Table 2 (continued)

Sample			Charred		Uncharred		Weights/
No.	Identification	Part	W	F	W	F	Comments
TR4-3	Liters Floated						1.0 L
50-78	Light Fraction Weight						1.95 g
cm	FLORAL REMAINS:						
	Rootlets					X	Numerous
	NON-FLORAL REMAINS:						
	Insect	Chitin				13	
	Rock/Gravel					X	Moderate
CC1-2	Liters Floated						0.8 L
50 cm	Light Fraction Weight						5.88 g
	FLORAL REMAINS:						
	Poaceae	Seed		1			<0.001 g
	Cheno-am	Embryo			3		
	Chenopodium	Seed			12	49	
	Cirsium	Seed				4	
	Cyperaceae	Seed			2		
	Rootlets					X	Numerous
	Sclerotia				X		Few
	CHARCOAL/WOOD:						
	Alnus-type	Charcoal		3			0.007 g
	Betula-type	Charcoal		2			0.001 g
	Salicaceae	Charcoal		1			<0.001 g
	Unidentifiable (small)	Charcoal		X			0.002 g
	Salicaceae	Wood				10	0.444 g
	Unidentified	Wood				X	0.329 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				9	
	Rock/Gravel					X	Few
	Snail				2	67	

W = Whole
F = Fragment
X = Presence noted in sample
g = grams

Table 3.—Index of Macrofloral Remains Recovered From Along the Teton River, Idaho

Scientific Name	Common Name
FLORAL REMAINS:	
Asteraceae	Sunflower family
Cirsium	Thistle
Cheno-am	Includes goosefoot and amaranth families
Chenopodium	Goosefoot
Poaceae	Grass family
Scrophulariaceae	Figwort family
PET Fruity	Fruity epithelioid tissues; resemble sugar-laden fruit or berry tissue without the seeds
CHARCOAL/WOOD:	
Alnus-type	Alder
Betula-type	Birch
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, and cypress
Juniperus	Juniper
cf. Prunus	Plum, Cherry
Salicaceae	Willow family; includes willow, cottonwood, aspen

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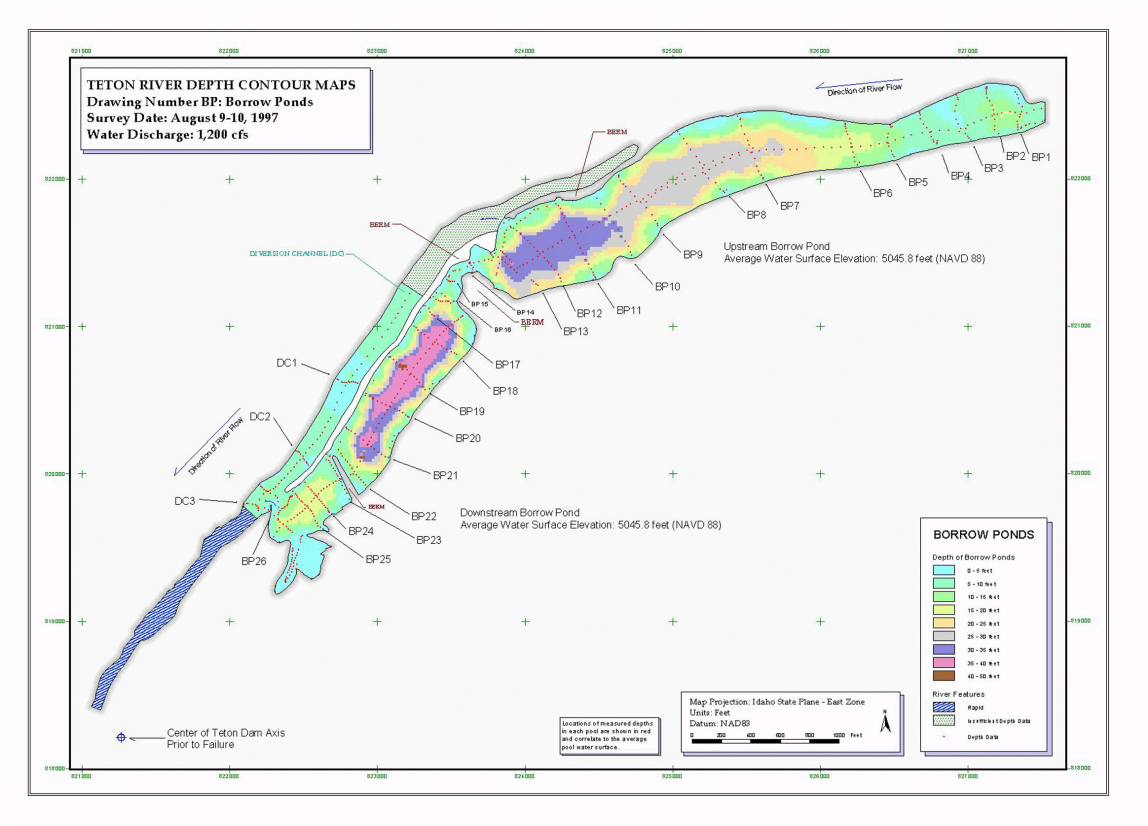
Bathymetric Maps of Teton River From Bitch Creek to Canyon Creek and Borrow Ponds

Bathymetric maps were prepared by Kurt Willie, Remote Sensing and Geographic Information Group, Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Note: All bathymetric maps are located on the enclosed compact disc.



Geomorphology of Teton Canyon From the Confluence With Bitch Creek to the Confluence With Canyon Creek

Note: This appendix provides a pool-by-pool description of the geomorphology of the Teton River canyon from the upstream extent of the former reservoir inundation area to five miles upstream of the Teton Dam site. This reach of the river was the most impacted from the landslides caused by the filling and subsequent drawdown of Teton Reservoir during the dam failure. Several cross section plots are referred to in the following text (surveyed in 1997-99) and can be located in Appendix E. Bathymetric maps that show the locations of cross sections, pools, rapids, and depths of each pool measured during field surveys are located in Appendix J. Travel times referenced in this section are discussed in the main report and presented in tables 12 and 13.

Bitch Creek

The confluence of Bitch Creek and the Teton River marks the upstream extent of the former Teton Reservoir inundation just before the failure of Teton Dam. Between Bitch Creek and the first pool backed up by a landslide-formed rapid, the river is shallow and the channel bed is armored with 3-inch to 6-foot diameter boulders. It was observed during 1999 field work (discharge of 670 ft^3/s) that the water depth in this reach was fairly uniform, approximately 2-4 feet in most places. A few shallow landslides are evident along the right canyon wall (looking downstream) in the downstream portion of this reach.

Pool 1

Pool 1, formed by a rapid caused by the dam failure, is the upstream-most pool in the former reservoir inundation area. Five cross sections, approximately 100 to 150 feet in wetted width, were measured in Pool 1 during the 1999 survey. The channel bed in this pool is lined with gravels, cobbles, and patches of sand. A large eddy lined with sand exists in the left side of the pool just upstream of rapid 1.

Pool 1 is relatively short, approximately 260 feet in length which results in a short water retention time (on the order of a few minutes). Pools with short retention times tend to not trap the majority of fine sediments (clay, silt, and sand) transported by the river system. However, pool 1 would likely act as a trap for gravel and cobbles. Maximum channel depths measured at each cross section range between 10 and 18 feet. The fact that pool 1 still has significant depths after 20 + years since the dam failure suggest that the gravel and cobble load of the Teton River is small. In addition, the channel bed of the Teton River upstream of pool 1 consists primarily of boulders. This also indicates the gravel load of the Teton River is limited. It is likely that the dominant size of river bed-material transported by the Teton River is sand.

This pool inundated a predam rapid that can be seen in the 1972 aerial photographs. Several submerged tree stumps were evident along the left side of the pool (looking downstream) at depths of 1 to 2.5 feet. Prior to the filling of Teton Reservoir, all of the trees below the maximum reservoir inundation (elevation 5,300) were cut, but the stumps were left in growth position.

Because the trees require dry ground to grow on, areas where tree stumps are now submerged provide an indication of the predam terrace surfaces. In addition, tree stumps indicate the extent that the water surface elevation of the river has increased, and/or the wetted channel width of the river has expanded.

Rapid 1

Rapid 1 is the upstream most rapid caused by the Teton Reservoir inundation. This rapid produces a 5-foot drop in water surface elevation. This rapid is a newly formed rapid originating from the left canyon wall during the Teton Dam failure. A separate rapid, slightly upstream of rapid 1, is evident in the 1972 aerial photographs. A debris chute that caused the formation of the rapid evident in the 1972 photographs can be seen in the 1997 aerial photographs. Although this rapid is now inundated by pool 1, the river channel constriction formed by landslide debris still persists. Just downstream of rapid 1, two cobble bars deflect the river flow. The water surface elevation through the cobble bars is fairly flat, with a small riffle just downstream causing an additional 2-foot drop in water surface elevation. This feature is not evident in the 1972 aerial photographs.

Pool 2

This pool is approximately 1,360 feet in length and has a short retention time also, a few minutes longer than pool 1. Seven cross sections, approximately 150 feet in wetted width, were measured in this pool during the 1999 survey. Several tree stumps can be seen in this pool approximately 3.5 to 4.5 feet deep from the base of the stump to the water surface at the time of the 1999 survey (discharge of 670 ft^3/s). There is a large amount of sand, gravel and cobbles along the channel bed in this pool. A relatively uniform water depth (average of 6 feet) was observed throughout the pool. This suggests that the pool has filled in to near capacity (for the given velocity and retention time of this pool) with sand since the dam failure in 1976.

Rapid 2

Rapid 2 was a pre-existing riffle that was enlarged following the dam failure by landslides originating along both canyon walls, but primarily from landslide debris from the right canyon wall. This riffle constricts the river channel to a greater extent today (1997) than prior to the dam failure. Rapid 2 produces a 13.5-foot drop in water surface elevation.

Pool 3

Pool 3 is approximately 2,390 feet in length and 10 cross sections were measured in this pool during the 1999 survey. This pool also has a short retention time, but is a few minutes longer than pool 2. In other words, the retention times increase in the downstream direction from pool 1 to pool 3 on the order of minutes. There are many variations in water depth throughout this pool. Shallow depths are inter-spaced with areas of significant water depths (up to 13 feet) with a

boulder and cobble-lined channel bed. However, where deeper portions of the pool exist, the width of the channel is much narrower (less than 50 feet as opposed to 100 feet in shallow areas) which results in higher velocities. As a result of the short retention time and high velocities throughout the pool, the pool is likely near capacity for storage of sand.

Cross sections 3-5 to 3-8 show some evidence of a terrace along river right that may now be inundated by 2 feet. At the downstream end of the pool in cross section 3-10, a terrace along river right is now inundated by 3 feet. These terraces may have been covered by landslide debris.

Rapid 3

Rapid 3 was also a pre-existing riffle that was enlarged by landslides induced by the dam failure. One riffle at the upstream end of the present location of rapid 3, and another at the upstream end of pool 4 existed prior to the dam failure and the formation of rapid 3. Rapid 3 was created by a rock slide from the left side of the canyon and causes a 11-foot drop in water surface elevation.

Pool 4

Pool 4, approximately 4,020 feet in length, is the longest of the nine pools in the Bitch Creek to Spring Hollow reach and has the longest retention time of over an hour. Fifteen cross sections were measured in this pool in the 1999 survey. At the upstream most end of the pool, the water depths range from 6 to 11 feet. A large landslide along the left canyon wall most likely contributed a large amount of debris to the channel bottom in the downstream 2/3 of this pool, resulting in the shallow depth areas and increased river stage. However, this landslide does not appear to have constricted the river channel. The maximum water depth in this pool of 15 feet is at a section near the center of the pool. The downstream half of this pool has a uniform channel bottom and water depth (average depth of 12 feet).

The majority of the pool has a sand-covered channel bottom. Rippled sand is evident in the downstream half of the pool which indicates small velocities. In addition, in the downstream half of pool 4, two debris chutes along the right canyon wall are evident in the 1972 aerial photographs. Debris from these chutes formed a constriction in the predam channel. Debris from these chutes appears to have been eroded out as the main channel was shifted to the right side due to the landslides along the left canyon wall. Terraces along river right are evident in the 1972 aerial photographs and are covered in places by landslide debris. Near the middle of pool 4 at cross sections 4-9 to 4-11, the top width seems to have increased significantly from 1972 conditions based on aerial photograph comparisons. The cross section plots show evidence that the river has inundated the terrace by up to 8-9 feet.

Three inundated tree stumps were observed in pool 4. At the upstream end of the pool near cross section 4-2 there is a tree stump along the right side submerged by 5.1 feet (from base of the stump to water surface at time of survey). The second tree stump, submerged by 2.7 feet, is along the left bank approximately 200 feet upstream from cross section 4-3. The third tree stump is very large, and is submerged to a depth of 6.7 feet at the downstream end of pool 4 along the left side just upstream of rapid 4.

Rapid 4

Rapid 4 is a previously existing rapid that was enlarged by extensive landslides caused by Teton Reservoir along the left canyon wall. The former riffle originated from a debris chute along the right canyon wall and caused a small constriction in the river channel. This rapid causes a drop in water surface elevation of 16 feet, but occurs over an extended distance of 1700 feet.

Pool 5

Pool 5 is approximately 2,780 feet in length. Fourteen cross sections were measured in this pool in 1999. The retention time in pool 5 is over an hour, a few minutes shorter than pool 4. Maximum measured channel depths at each cross section in pool 5 are significant (majority range from11 to19 feet). It was difficult to observe the channel bottom during the 1999 survey. The majority of sediment appeared to be silt and clay with a few boulders, most likely derived from local landslide sources. The sediment distribution in pool 5 suggests that the majority of sand transported by the river is being trapped upstream of rapid 4. On the basis of sediments observed along the channel bed, measured pool depths and channel widths, and computed water travel times, pools 1-3 appear to be near the maximum storage capacity for sand, while pool 4 is in the process of reaching this stage.

At the downstream end of pool 5 at cross section 5-10 and again at 5-14, a narrow terrace is inundated along the left side of the river by 10-12 feet. At cross sections 5-6 to 5-8, a terrace is again evident along the left side of the river and has been inundated by 4-6 feet. At cross section 5-4, a terrace along the left bank is inundated 2 feet.

Rapid 5

Rapid 5 is a newly created rapid caused by the dam failure. Rapid 5 causes a drop in water surface elevation of 8.5 feet. This rapid was formed by debris from a landslide along the left canyon wall. A few boulders are evident in the location of rapid 5 in the 1972 aerial photographs. While a rapid is not evident in the 1972 aerial photographs at this location, the constricted river channel width is similar to existing conditions.

Pool 6

Pool 6 is divided into two pools by a short rapid (rapid 6), followed by a small riffle (riffle 6). The first pool, 6A, is the main part of the pool and is approximately 1,870 feet long. Pool 6B is a very short section, less than 100 feet long. There were nine cross sections measured in pool 6A, and 2 cross sections measured in pool 6B during the 1999 survey. Maximum channel depths at each cross section are again significant in pool 6A, ranging between 13 and 20 feet. Maximum channel depths measured in pool 6B are less than 5 feet. The retention time in pool 6a is near 50 minutes, while in pool 6B it is only a few minutes.

There are several eddies in pool 6A that are filled with silt, clay, and large amounts of aquatic vegetation. In the 1972 aerial photographs, a vegetated island is evident just upstream of the current location of rapid 7. There may be evidence of this vegetated island in cross section 6-9. A terrace is evident along the left side of cross section 6-5 that is inundated approximately 9 feet. Another terrace is evident along the right side of the river in cross section 6-7 that is inundated 8 feet.

Rapid 6 and Riffle 6

Rapid 6 is a newly formed rapid caused by the Teton Dam failure that results in a 6-foot drop in water surface elevation. Riffle 6 causes an additional 3-foot drop in water surface elevation. Rapid 6 was formed from landslide debris originating from the left canyon wall, and riffle 6 debris originated from the right canyon wall.

Pool 7

Pool 7 is aproximately700 feet long. Five cross sections were measured in this pool during the 1999 survey. Maximum measured channel depths at each cross section average 8 feet in the upstream half and 4 feet in the downstream half of the pool. The retention time in pool 7, and in pools 8 and 9, is only a few minutes. During the dam failure, several landslides occurred along the right and left canyon walls in this reach that contributed sediment to the river. There were no rapids or riffles evident in this reach in the 1972 aerial photographs.

Rapid 7

Rapid 7 is a newly created rapid caused by the dam failure that causes a drop in water surface elevation of 4 feet. The rapid was formed from landslide debris originating from both canyon walls.

Pool 8

Pool 8 is relatively short, approximately 520 feet long. The two cross sections measured in this pool during the 1999 survey have a wetted width of 150 feet. The average maximum measured

channel depth is 8 feet. At the downstream end of pool 8, a longitudinal island is evident in the 1972 aerial photographs. The material from this island is still visible today just upstream of rapid 8. Large boulders were observed along the left side of the river at cross section 8-2.

Rapid 8

Rapid 8 is a newly formed rapid caused by landslides induced along both canyon walls by the dam failure, but primarily from the left. This rapid causes a drop in water surface of 2.5 feet. In the 1972 aerial photographs, an island just upstream of this rapid appears to have created a small riffle in the river channel.

Pool 9

Pool 9 is approximately 520 feet long. Three cross sections were measured in pool 9 during the 1999 survey that have a wetted width of 150 feet. The maximum measured channel depth is 11 feet in the upstream half of the pool and 8.5 feet in the downstream half of the pool. There are several landslides along the left canyon wall in this pool that have contributed sediment to the river channel. A tree stump that was inundated approximately 1 foot was observed along the left side of the channel between cross sections 9-1 and 9-2.

Rapid 9 at Spring Hollow

Landslides resulting from the filling and subsequent failure of Teton Dam are evident on the left canyon wall at the mouth of Spring Hollow (photograph A-11). Evidence in older photography indicates that the landslide resulting from the 1976 failure occurred at a location in the canyon that had been the site of previous landslides. Prior to the dam, there was a mid-channel bar formed by alluvium from Spring Hollow and the main channel of the Teton River flowed along the left side of the canyon. Landslides on the left side of the canyon blocked this channel and coarse debris from the slide created a rapid immediately upstream of Spring Hollow (rapid 9). However, the channel configuration at the mouth of Spring Hollow prior to the dam had been largely controlled by the sediment delta related to the tributary drainage.

Pool 10

Pool 10 is located immediately downstream of Spring Hollow. Three cross-sections were measured in the pool in July 1998. The pool is approximately 770 feet long. Cross-section 10-1 is located just downstream from the longitudinal island at Spring Hollow. The bed and banks in this part of pool 10 appear to have been elevated by relatively finer-grained debris transported downstream from the slide upstream of Spring Hollow that forms rapid 9. Cross-section 10-2 is located in the middle of pool 10. The left portion of this cross section (both channel bed and bank) also appears to be elevated from predam conditions by finer-grained

material originating from the slide debris. Cross-section 10-3 is located at the downstream end of pool 10. The entire cross section is similarly elevated, but by landslide debris from the right side of the canyon that forms rapid 10.

An extensive low terrace was present along the right bank between cross-sections 10-2 and 10-3 before the inundation by the reservoir. The terrace was subsequently eroded due to the change in the channel configuration upstream and inundated by 3 to 4 feet in the pool backed up by rapid 10 and the addition of landslide debris to the channel.

Rapid 10 (Riffle)

Rapid 10 actually consists of two small riffles with a total drop across the pair of at least 1.5 feet. Both riffles are formed primarily of debris from a shallow landslide on the right side of the canyon. No constriction or rapid was present at this location prior to the inundation by the reservoir.

Pool 11

Four cross-sections were measured in pool 11 in July 1998, cross sections 11-1, 11-2, 11-3, and 11-4. The pool is approximately 2,010 feet long. Prior to inundation by the reservoir, the reach of the river now in the upstream part of pool 11 contained numerous large boulders that appear to have come from rock falls on the right canyon wall. Numerous old landslide scars in this reach are also evident in older aerial photography. In addition, a large island at approximately the present location of rapid 11 deflected the river channel toward the right side of the canyon. A narrow terrace was present along the entire right side of the river through pool 11 to the island. The boulders, island, and low terraces are now shallowly submerged.

The cross section surveys show two predam terraces now submerged in pool 11. The older of these terraces is now submerged to a depth of 5 feet. The younger terrace, visible in the older aerial photography, is now submerged to a depth of 2.5 feet. The presence of an older submerged terrace suggests that an earlier landslide, perhaps the remnant of which forms the mid-channel island in the older photography, caused an increase in pool depth prior to the dam failure. Cross-section 11-3 may provide evidence of old landslide debris (pre-1976) in the left half the section. On the basis of the cross-section surveys, the channel bottom through this reach was not significantly affected by landslide debris or redistribution of landslide debris, as was pool 10.

Rapid 11

Rapid 11 was formed by landslides from both sides of the canyon and creates a 5-foot drop (photograph A-37). The older aerial photography shows an old landslide scar on the right side of the canyon at this location and a few very large boulders constricting the channel and creating a riffle.

Pool 12

Seven cross-sections were measured in pool 12. The pool is approximately 1,940 feet long. On the basis of a submerged terrace along the left side of the channel, the pool elevation has increased by 2.5 feet. This terrace is evident in cross-section 12-1, and a submerged mid-channel bar is evident in cross-section 12-6 and possibly 12-5. The older aerial photography shows a low terrace on the left side of the channel with a backwater channel. Most of the terrace is above the water surface and covered with vegetation. A mid-channel bar is evident in the older aerial photography near the location of cross-section 12-6 which is now inundated by about 2.5 feet. The mid-channel bar can still be seen as a submerged bar in the 1997 photos. However, there is now an additional transverse bar superimposed on the mid-channel bar (photograph A-36). The source of sediment for this new transverse bar is the landslides originating from the left side of the channel. It appears that landslide debris blocks the channel on the left side of the canyon and buried the downstream end of the mid-channel bar. The older aerial photography also shows evidence of a wide terrace on the right side of the river in the downstream half of pool 12. In the 1997 aerial photographs, the downstream end of this terrace appears to be buried by landslide debris from the left side of the canyon.

Cross-sections measured in pool 12 and 1997 aerial photographs show no evidence of significant deposition along the channel bottom as the result of the 1976 landslides. However, the left side of the channel between cross-sections 12-5 and 12-6 was apparently blocked by landslide debris. Erosion of that debris has partially reformed the channel.

Rapid 12

Drop in the water surface through rapid 12 was measured at about 3 feet. The source for this rapid appears to be from 1976 landslides on the left side of the canyon (photograph A-35). In the 1972 aerial photographs, a few boulders are evident above the water surface at this location along both edges of the channel, creating a riffle, but no large rapid exists. The 1997 aerial photos show that the present channel has a constricted width through the rapid relative to the channel width in 1972. An overflow channel (accessed only by high flows) has developed along the right edge of the canyon wall.

Pool 13

Pool 13 is approximately 1,100 feet long. There is a long, narrow terrace in the upstream portion of the pool on the right side. Neither of the measured cross-sections (13-1 and 13-2) show evidence of this terrace. The 1997 aerial photos show a 1976 landslide may have deposited material directly on this right terrace. This may be due to their location within the pool (i.e., XS 13-1 is at a diagonal and may not reach the right bank). Cross-section 13-1 appears to have landslide debris originating from a 1976 landslide on the right side. Cross-section 13-2 is located at the top of the rapid.

Rapid 13

The total drop through rapid 13 is about 5 feet. Rapid 13 is formed by two slides from the left canyon wall and material from an ancient slide that was re-mobilized. Prior to the dam, there is a mid-channel bar at the present location of the middle of rapid 13. Scattered boulders appear above the water surface along the edge of the channel forming a riffle, but no rapid is observed. These boulders appear to have originated from rock falls on the right side prior to 1972. To recreate predam (1972) conditions for hydraulic modeling, rapid 13 cross-sections could be widened.

Pool 14

Pool 14 is approximately 1,700 feet long. There appears to be relatively little change in the channel through this reach due to the 1976 landslides. There are several shallow slides at the downstream end near rapid 14. One of these slides forms a mid-channel bar. Cross-section 14-1 shows evidence of a submerged terrace at a depth of 3-4 feet. This terrace can be seen along the right bank in the 1972 aerial photographs near the upper end of pool 14. The 1972 aerial photographs show a submerged mid-channel bar at the approximate location of cross-section 14-1. This feature is observed in the 1997 survey at cross-section 14-1.

Rapid 14

There is presently a drop at this location about 3.5 feet through this rapid. Prior to inundation by the reservoir, there is no evidence of a rapid. The rapid appears to have been formed from 1976 landslide deposition from both the right and left sides of the canyon, although, most of the debris forming the rapid came from the right side of the canyon.

Pool 15

Pool 15 is approximately 1,480 feet long. Prior to the dam a narrow terrace was present along the right bank of the pool. This terrace had a few trees and lots of low vegetation. The construction of Linderman Dam formed a pool, which submerged this terrace. In the 1972 aerial photos, Linderman Dam was backing up water near the upstream end of pool 15. The 1997 aerial photos show evidence that this terrace is still submerged, but due to the 1976 landslides instead of Linderman Dam (the remainder of this dam no longer acts as a hydraulic control upstream of rapid 16). During the 1998 field survey, it was noted that the base of a juniper tree at the upstream-most end along the right bank of pool 15 was submerged to a depth of approximately 3-5 feet (photograph A-34). Note that the juniper tree was growing just upstream of the pool formed by Linderman Dam.

Cross-section 15-1, located at the top of pool 15, was not surveyed across the right half of the channel and cannot be used to verify the existence of a submerged terrace. However, cross-sections 15-2 and 15-3 both show evidence of the submerged terrace on the right side. From this data, this terrace is submerged 3-4 feet, which is consistent with the aerial photographs. None of

these sections appear to have been affected by 1976 landslide debris, although the pool is deeper than before the 1976 landslides. The 1972 reservoir basin topographic map shows the approximate elevation of what is now pool 15 to be about 5156 feet. The current average elevation of pool 15, based on survey data, is about 5159 feet. This is a 3-foot increase over the predam conditions. This 3-foot increase agrees with observations made in July 1998, of a juniper tree rooted on a low terrace are submerged to a depth of about 3 feet (photograph A-33).

Rapid 15

Rapid 15 is made up of two rapids formed by a large slide from the left canyon (SE) wall. Rapid 15 is fairly long, about 3-4 channel widths in length with a measured 6.0 feet of drop across the entire rapid. There is no evidence of a rapid in the 1972 aerial photographs. There is an overflow channel forming at the upper left side of the rapid. Boulders in slide debris exhibit thick calcium carbonate coats indicating that debris forming the rapid was stable for tens of thousands of years prior to failure.

Pool 16

Pool 16 is approximately 680 feet long. The 1972 aerial photographs show a low terrace along the right bank. This terrace is an extension of the terrace evident in pool 15. The terrace is supporting trees along the right bank in 1972. This terrace is in the 1997 aerial photos. The 1997 cross-section data shows evidence of a submerged terrace on the left bank in cross-section 16-1. There is also a break in channel slope evident on the depth charts in cross-section 16-2 and 16-3. Along the right bank, small shallow slides from 1976 are evident but none of these cross-sections appear to have been affected by 1976 landslide debris. Measurements of the water depth over the inundated terrace indicate that the pool depth is elevated by approximately 3 feet.

Rapid 16

The drop through this rapid is about 2.5 feet. There is no evidence of this rapid in the 1972 aerial photographs. The source for this rapid is from a series of relatively shallow landslides on the left side of the canyon. This rapid has substantially constricted the channel. The water surface elevation in the pool upstream of Linderman Dam (in 1972) was estimated to be about 5155 feet. The water surface elevation of pool 16 was measured in 1997 to be an average of 5153 feet. This means the pool elevation today is approximately 2 feet lower than it was in 1972. Therefore, Linderman Dam served as a greater hydraulic control in 1972 than the combined effect of what is left of Linderman Dam and rapid 16.

Pool 17

Pool 17 is formed behind the remnants of Linderman Dam and an alluvial fan delta from Milk Creek and forms the left abutment of Linderman Dam, which runs into Teton River in the vicinity of Linderman Dam. Pool 17 is approximately 790 feet long. The delta formed by Milk Creek (shown as submerged in the 1972 aerial photographs) is substantially exposed in the 1997 aerial photographs. Portions of the delta downstream of Linderman Dam are now submerged in the 1997 photos. There are no apparent landslides from 1976 along either bank of this pool. Cross-section 17-1, just upstream of the dam, shows some evidence of the submerged portion of the delta.

Pool 18

This is a short pool, about 520 feet long, directly downstream of Linderman Dam. The 1972 aerial photos show an alluvial fan and delta on the left side of the channel by Milk Creek. This alluvial fan and delta have been highly modified by the construction activities for Linderman Dam. The left bank in the present location of pool 18 appears to have been excavated creating a broad low bench at or near the 1972 water surface elevation. In the 1997 aerial photos this bench is inundated by as much as 4 feet. Cross-section 18-1, just downstream of the dam at the top of the pool, shows a deep scour hole on the right side about 27.5 feet deep. The location of this hole is consistent with the location of the outlet/spillway of Linderman Dam and the position of the pre-Linderman Dam channel. There is also a terrace on the left side inundated by about 8 feet. This terrace may have been created by excavation during the construction of Linderman Dam. Cross-section 18-2 also shows a broad terrace inundated by about 4 feet on the left side. The deep portion of this cross-section reaches a depth of about 16 feet. The alluvial fan delta formed at the mouth of Milk Creek has deflected the course of the Teton River to the right side of the canyon. Rock straths preserved about 28 feet above the present water surface elevation provide evidence that the location of the Teton River channel in this reach has been largely controlled by deposition from Milk Creek. The water surface elevation in pool 18 is estimated to have increased about 4 feet above predam conditions. This is confirmed by the data in cross-section 18-2 and the hydraulic drop through Linderman Dam.

Rapid 18

The measured drop through this rapid is about 6.0 feet. There is no evidence of a rapid of this size in the predam aerial photography, but there is a minor riffle evident at the current location of the rapid indicating a shallow channel depth. This riffle is probably the result of an older landslide on the left bank at the upstream end of the present rapid. A slide at the same location was triggered by the 1976 landslide and destabilized material that was at least late Pleistocene in age. The 1976 landslide was orders of magnitude larger in terms of volume and deposited debris into the river creating a rapid and severely constricted the channel. The debris has constricted the channel by at least half the channel width.

Pool 19/20

Pools 19 and 20 are separated only by a shallow set of riffles. Pool 19 is approximately 2,000 feet long and pool 20 is approximately 450 feet long. A narrow terrace on the right side of the river downstream of the present location of rapid 18 has been completely eroded. This erosion was likely caused by the redirection of flow in the main channel as a result of the landslide and increased flow velocity due to the channel constriction caused by the rapid. Survey data were collected in 1997 in both pools. A low terrace is evident along the left and right side of the present pools. Also, several large boulders are evident in the middle of the channel resulting from rock falls on the right side of the canyon. The river channel through pools 19 and 20 prior to the 1976 failure of Teton Dam was characterized by a channel of uniform width. No major rapids or riffles were present through the reach. However, the channel was punctuated by small mid-channel bars that had formed downstream of large boulders, the product of rock falls from the right canyon walls. In addition, prior to inundation by the reservoir, a low terrace was present along both sides of the channel. The 1997 aerial photos show evidence that the terrace on the right side has been eroded and the material transported downstream. The landslide on the left side of the canyon that formed rapid 18 deflected the channel to the right side of the canyon and caused erosion of this terrace.

Cross-section 19-1 is a relatively wide section with a channel width of 300 feet and is located at the upstream end of pool 19. This cross-section shows a submerged mid-channel bar that is evident in both the 1972 and 1997 aerial photos. Cross-sections 19-2 and 19-3 are about half the channel width of cross-section 19-1. Cross-section 19-4 is located just upstream of the start of the riffles and is about 200 feet wide. Cross-section 20-1 is located in the short pool between the end of the riffles and the beginning of the rapid.

Rapid 19/20 (Riffles)

These rapids were created by a very large landslide on the left canyon wall and formed a set of four constrictions with a small pool separating the first three riffles from the fourth. The combined drop through the first three riffles is about 7.0 feet (rapid 19). The drop through the last, and biggest rapid in the series is about 4.5 feet (rapid 20). Evidence in the 1972 photos indicates that these islands are formed of rock debris from the right canyon wall. However, the channel is not constricted other than the mid-channel bar splitting stream flow. The 1997 aerial photos show large constrictions for each of the 4 rapids in the series. All of the rapids formed as the result of the 1976 landslides along the left bank.

Pool 21

Pool 21 extends through a straight reach of the canyon, which is oriented in an NE-SW direction, for approximately 1,800 feet. No landslide scars were observed along either side of the canyon in the 1957 or 1972 aerial photos. The only landslides in this reach of the river that resulted from the 1976 dam failure are those forming rapids 20 and 21. Prior to the dam failure, long narrow terraces were present on both sides of the river through pool 11. In

addition, numerous mid-channel bars and large boulders were present. In the 1997 aerial photographs, the terraces have been inundated by the pool water surface ponding behind rapid 21.

Four cross-sections were surveyed across this pool. Cross-section 21-1, located at the top of the pool, shows no evidence of submerged terraces or coarse landslide debris. Cross-section 21-2, in the upstream portion of pool 21, shows a submerged bar in the center of the channel at the approximate location of the shallow bar evident in the 1972 aerial photos. Data from cross-section 21-3 suggest that the submerged terrace is inundated to a depth of about 1 foot. The channel bottom along cross-section 21-4 (from the depth chart) is very flat. On the basis of the measured cross-section data, it appears that the terraces are submerged by a minimum depth of 1-2 feet.

Rapid 21

The measured drop through this rapid is 3 feet. The 1972 aerial photos show a large talus slope on the right bank which was the source of a few boulders in the channel just upstream of the current location of the rapid. However, there was no rapid at this location before the dam failure. Landslides on both the right and left sides of the canyon caused a rapid to form and the river channel to be constricted. Debris forming the landslide from the left side of the canyon is comprised in large part of re-mobilized alluvial fan sediment at the mouth of a small tributary herein referred to as County Line Creek. The alluvial fan at this location prior to the failure deflected the river channel to the right side of the canyon.

Pool 22

Pool 22 is very short at a length of approximately 730 feet. The 1972 aerial photographs show a narrow terrace on both sides of the pool. No pre-1976 landslide scars are evident. In this reach, however, numerous boulders in the channel and mid-channel bars are present in the 1972 aerial photographs.

Two cross-sections were measured in pool 22. Cross-section 22-1 is relatively narrow (150 feet) while cross-section 22-2 is much wider (300 feet). The bottom of cross-section 22-2, which is just upstream of rapid 22, is very rough most likely reflecting coarse landslide debris in the channel.

Rapid 22

Rapid 22 was formed by a very large landslide from the left canyon wall (photograph A-30). Stream flow is currently split around a mid-channel island formed of landslide debris and a previously existing mid-channel bar. The rapid is located on the right side of the island. Landslide debris blocked the left side of the channel and buried the existing mid-channel bar. The measured drop through this rapid is about 3.0 feet. Three mid-channel bars in the current location of rapid 22 existed in the channel prior to the 1976 failure. The two islands located where the current rapid is were longitudinal - one about one channel width long. These islands probably formed as

bars on the downstream side of boulders that fell into the channel from the adjacent canyon walls. This idea is supported by the presence of other large boulders in the channel on the 1972 aerial photographs.

Pool 23

Pool 23 is approximately 1,500 feet long (photograph A-29). Through the pool, there are numerous landslides on the left side of the canyon with a debris island located about 1/3 the length of the pool from rapid 23. With the exception of a small rock fall located on the right side about midway through the pool, there are no significant landslides on the right side of the canyon. Low, narrow terraces were present along both banks of the channel at the present location of the pool.

Numerous cross-sections were measured through pool 23. The thalweg portion of cross-section 23-1 is 9 feet deep and narrow (about 25 feet). This narrow deep portion may be the result of scour downstream from rapid 22. Cross section 23-2, located just upstream from the debris island, is relatively shallow (maximum depth of 5 feet) and the bottom is very rough. This is undoubtably due to the existence of mid-channel bars in the area prior to the dam failure, landslide debris, and possibly material eroded by scour downstream of rapid 22. Cross sections 23-3 and 23-4 are both relatively deep (10 to 11 feet) and smooth. None of the cross sections show evidence of submerged terraces, except for cross section 23-1 which shows a narrow terrace along the right bank submerged to a depth of 1 foot.

Rapid 23 (Chute of Riffles)

Rapid 23 is a long (approximately 1,400 feet), narrow section of channel comprising a major rapid with 3.5 feet of drop and a series of riffles just downstream of the major rapid that account for an additional 10 feet of drop. The series of riffles end just downstream of a tributary stream and alluvial fan, herein referred to as Wheat Creek (after survey control “Wheat” which is located on the Canyon rim). The gradient through this reach does not appear to have significantly changed as a result of the 1976 landslides. At the downstream end of the rapid, there is a triangular shaped island. There are no landslides on either side of the canyon at the location. It appears that the island formed from sediment transported into the reach from the landslides upstream.

Pool 24

This pool begins just downstream of the long series of riffles (downstream of pool 23) that are approximately 2,100 feet long. Pool 24 is approximately 2,850 feet long. There is a small mid-channel bar at the upstream end of the pool. This mid-channel bar apparently formed as a result of re-mobilized landslide debris upstream and on the adjacent canyon walls. The pool makes a sharp bend (100 degrees) to the right. A large point-bar terrace is present along the right canyon wall. This is the largest terrace along the river between this location and Spring Hollow. On the basis of its elevation above the present channel, and observations of particular soil properties exposed along the river, the terrace is interpreted to be early Holocene to late Pleistocene in age (<14,000 years old). The surface morphology of the terrace is basically unchanged relative to the

pre-1976 failure configuration with the exception of the vegetative cover. Prior to the dam failure, a narrow, terrace inset below the older terrace existed along the right bank. In addition, two debris fans on the left side of the canyon opposite the terrace constricted the river in three places and produced a series of riffles through this reach. These riffles do not exist at this location currently, in part because of an increase in the pool elevation behind rapid 24.

Five cross-sections were measured in this pool. Cross section 24-1, at the upstream end of the pool indicates that the channel is relatively shallow with a maximum depth of 4 feet. The bottom of cross section 24-2 is also relatively shallow, particularly along the left side of the channel where it is only 1.2 feet deep. This reach of the channel is interpreted to be an eddy bar formed from redistributed landslide debris apparently transported by the river from landslide sources upstream. Cross sections 24-4, 24-5, and 24-6 do not show any noteworthy features. A point bar just upstream of rapid 24 extending upstream into pool 24 remains relatively unchanged as a result of inundation by the reservoir.

Rapid 24

Rapid 24 is formed by a large landslide from the left canyon wall just downstream of an early Holocene or late Pleistocene terrace. The measured drop through the rapid is 3.5 feet. A small riffle appears to have existed at this location prior to the 1976 dam failure. The change in water surface elevation in pool 24 due to this rapid was enough to inundate the toe of the debris chutes evident in the 1972 aerial photography.

Pool 25

Pool 25 is the longest pool (5,220 feet) in the reach of the river between Spring Hollow and Canyon Creek. Through the entire length of the pool, the left canyon wall is marked by extensive landsliding. With the exception of one large slide approximately midway in the pool, none of the slides appear to seriously impact the channel other than moving easily eroded sediment to a position adjacent to the river. Through the length of the pool, the river rounds three bends. All three of these bends have either a low terrace or point bar on the inside of the bend. There are also low, narrow terraces along the straight reaches between bends on both banks. In the lower reach of pool 25, the canyon walls are marked by ancient landslide scars. There is evidence of a large landslide scar at the present location of the rapid in the 1957 and 1972 aerial photographs. Several debris fans also existed on the left side of the canyon between the second bend and third bend, numerous riffles are evident in the 1972 aerial photos through the length of pool 25.

Results of the 1997 and 1998 field surveys show evidence of all of the previously existing (pre-1976) terraces and bars are partially inundated. Cross-section 25-1, which is located at approximately the center of the first bend, shows evidence of a new eddy bar along the left bank. This bar was formed by redistribution of landslide debris transported from upstream. Cross-section 25-3, shows a submerged terrace along the inside bend (left side) at a depth of 1-2 feet and a submerged bar or terrace along the inside bend (left side) at a depth of 4-5 feet. Cross-section 25-4, located near the downstream end of the first bend, shows a submerged terrace on both sides of the channel with a break in slope at about 3.5 feet. There are landslides evident

along the left side of the downstream portion of this first bend. A small amount of debris from these landslides reached the left side of the channel, but at present do not significantly impact the river channel.

Cross-section 25-5, located in the upstream portion of the second bend, also shows an inundated terrace on the inside bend (right bank) at a depth of approximately 3.5 feet. The left bank terrace is buried by slide debris. Cross-section 25-6, located just downstream from the middle of the second bend, crosses a point bar on the inside bend (right bank) inundated by a depth of 3.2 feet. There are no significant landslides along either canyon wall through the second bend. With the exception of the larger slide near cross-section 25-5, the slides that were mapped on the 1976 landslide maps along the left canyon wall had minimal impact on the channel.

Cross-section 25-7 is located between the second and third bends. The channel bed of this cross-section does not appear to be affected by the 1976 landslide debris. Similarly, cross-section 25-8 is relatively unaffected by landslide debris and is rectangular in shape with a maximum depth of 12.8 feet. Cross-section 25-9, just upstream from rapid 25, is a shallow cross-section with a maximum depth of 7 feet and a very rough bottom. This suggests that landslide debris occurs on the channel bed. This is supported by geomorphic evidence indication that the large landslide on the left canyon wall now forming rapid 25 crossed and completely blocked the channel.

Rapid 25

Rapid 25 is formed by a large landslide from the left canyon wall. The measured drop through this rapid is about 3.0 feet (photograph A-28). There is evidence of several riffles in the reach downstream of rapid 25 in the 1972 aerial photos. Rapid 25 occurs at the same location as a very extensive ancient landslide. Several older landslide scars are apparent in the 1957 and 1972 aerial photographs. The riffles present at this location prior to the inundation by the reservoir may in part represent the remnants of older landslide debris.

Pool 26

Pool 26 is approximately 2,360 feet long and consists of 2 straight sections joined by about a 45-degree bend to the left. Around the bend a vertical rock wall exists on the left and a narrow vegetated terrace is evident on the right. The 1972 aerial photos show a large landslide scar on the left side of the canyon just upstream of rapid 26. The landslide created a large debris fan that deflected the channel. A narrow terrace along the left bank widens across the toe of the debris fan. A terrace along the right side of the channel was also evident through the reach, but narrows at the debris fan. In the 1997 aerial photographs, a new landslide is evident immediately upstream of the old landslide scar which constricts the channel. There are also several minor slides along the right side of the canyon, but they appear to have little impact on the channel. A submerged bar is present along the right side of the channel from rapid 25 through the bend. Another submerged terrace is evident on the left side downstream of the bend and upstream of the new landslide. Several additional submerged bars can be seen in the downstream end of this pool near rapid 26. The 1997/1998 survey shows the increased water surface elevation has generally increased top widths throughout the pool except at the constriction of the new landslide.

Cross-section 26-1 is located in the upstream portion of the pool and is relatively narrow with a width of 125 feet. The left side of the cross-section is very steep. Cross-section 26-1 shows submerged terraces are evident on the right side to a depth of 3 and 10 feet. Cross-section 26-1 has a maximum depth of 16.5 feet. Cross-section 26-2 is slightly skewed in the downstream direction which accounts for a much wider top width of more than 300 feet and has a maximum depth of 17.3 feet. Cross-section 26-2 shows a submerged terrace on the right of approximately 3 feet in depth. Cross-section 26-3 shows a relatively smooth channel bed, is relatively narrow with a top width of 175 feet, and a maximum depth of almost 19 feet. No terrace is evident on either side of the cross-section. Cross-section 26-4 is a relatively narrow V-shaped section with a width less than 150 feet and shallow with a maximum depth of 8.5 feet. This cross-section was likely filled in with coarse debris from the 1976 landslide on the left side of the canyon. Cross-sections 26-5 and 26-6 are near rapid 26, are shallow and very rough. This indicates presence of coarse landslide debris on the channel bottom. The maximum depth in cross-section 26-5 is about 9.6 feet and in cross-section 26-6 is about 6 feet.

Rapid 26

This rapid has a measured drop of about 3.5 feet that only constricts the channel a small amount (photograph A-27). The 1997 aerial photos show evidence that this rapid was formed from a 1976 landslide on the right side with small amounts of material from the left side. The 1972 aerial photos show no evidence of a rapid at the same location, but do show a large longitudinal island just downstream.

Pool 27

This pool is very short (500 feet) and is fairly wide (250 feet) (photograph A-25). There are no landslides evident in the 1997 aerial photos between rapids 26 and 27. In the 1972 aerial photos there is a terrace along the right side of the pool and a vegetated island in the middle of the pool. There is also a bar - half of which is submerged that extends from the right bank diagonally to the downstream end of the island. The island combined with the bar makes a V-shape feature in the channel. In 1997 the island and bar are completely gone. Cross-sections 27-1 and 27-2 show the current pool to be about 13 feet deep.

Rapid 27

In the Spring Hollow to Canyon Creek reach, this rapid has the largest measured drop of over 16 feet (photograph A-21). This rapid is not evident in the 1972 aerial photos, although a long riffle is present through the reach now under pools 26 and 27. The rapid was formed by several large landslides on the left bank (photograph A-22, A-24). Downstream of the rapid, several constrictions and islands are evident in both the 1972 and 1997 photos - although they are in different shapes and positions. The islands are mapped on the landslide maps as being composed in part as landslide debris, but it is apparent from pre-dam photography that these islands existed prior to the inundation of the canyon by the reservoir. It is possible that at the time the landslide mapping was being undertaken, that debris from upstream landslides was being transported downstream where it was deposited on existing bars.